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THREE-AXIS DYNAMIC SIMULATION OF HELICOPTER ANGULAR MOTION FOR --ETC(U)

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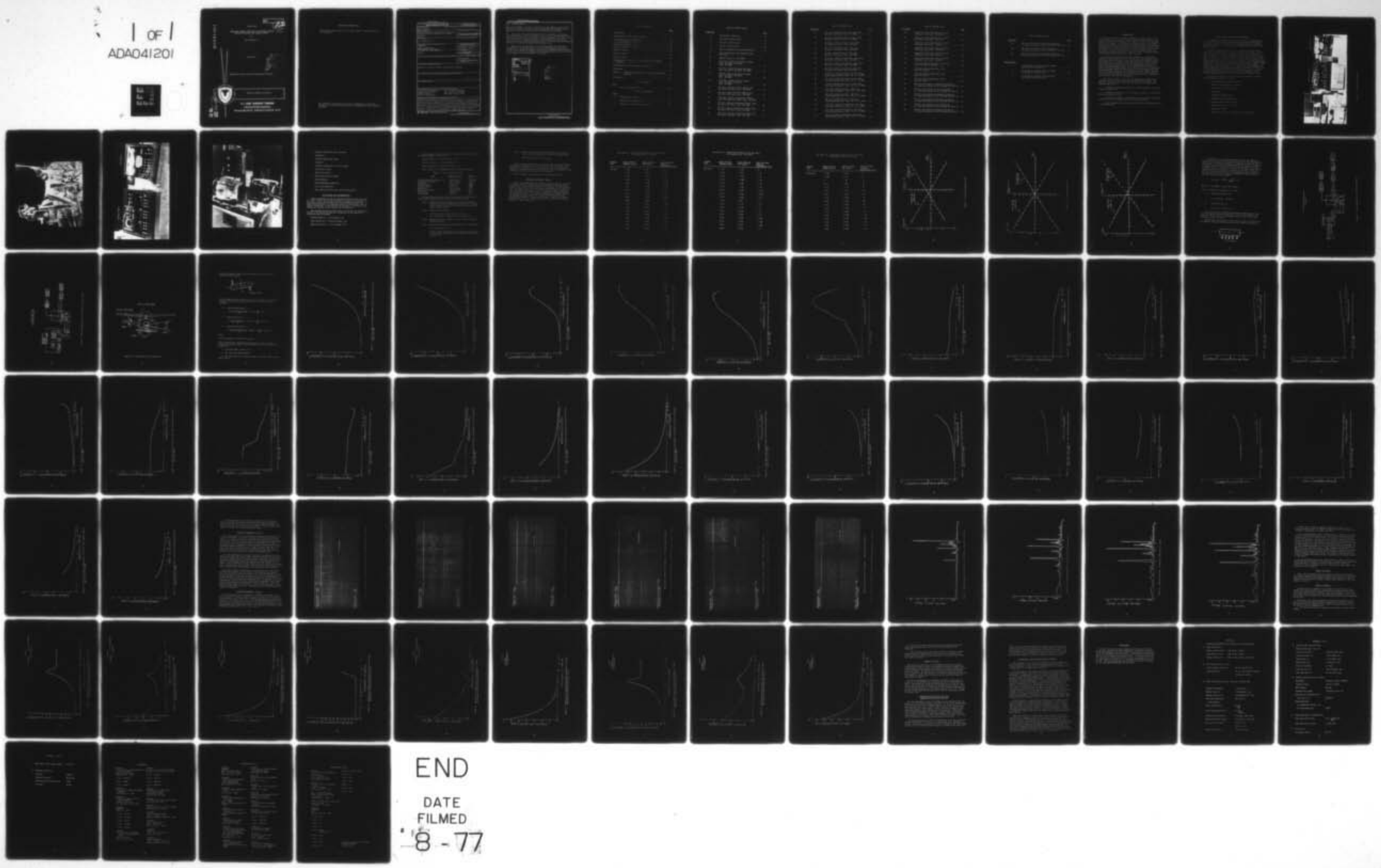

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THREE-AXIS DYNAMIC SIMULATION OF HELICOPTER ANGULAR MOTION FOR TESTING FIRE CONTROL MATERIEL

by

Eli Florence, Jr.

April 1977

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Technical Support Directorate

U.S. ARMY ARMAMENT COMMAND
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report describes a program which was conducted to develop improved testing methods for helicopter fire control acceptance testing by providing meaningful simulation of angular motions within the laboratory. Tests were conducted on a Flight Motion Simulator (FMS), which is hydraulically actuated, operable in both manual and tape modes, and constructed to handle individual test specimens no larger than twenty inches in diameter. Using a pre-recorded tape of angular motion

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20. ABSTRACT (Cont)

measurements were made in the AH-1G "Cobra" helicopter and test criteria from existing helicopter vibration specifications, data was obtained of the machine's operation in both the tape and manual operating modes.

Evaluation of the data indicates that it is possible to simulate helicopter motion (of up to 50 Hertz) on the table of the FMS by playing a pre-recorded tape of helicopter motion through the FMS's tape input. It is also possible to reproduce manually the displacement and acceleration curves of motions (limited by frequencies up to 50 Hertz) that are presently specified for helicopter mounted instrumentation.

Analysis of the performance of the FMS revealed that two design weaknesses in the present system could be considerably mitigated by re-design of the simulation system to provide more stiffness in the structure of the table, and by redesigning the system electronics so that DC and very low frequencies cannot be applied to the table.

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INTRODUCTION

The very nature of Helicopter equipment presupposes that it is, during operation, subjected to complex vibration induced forces. Small angular movements of the sighting instruments result in large sighting errors at the target. Fire Control instruments have precise sighting accuracy requirements and must function satisfactorily in the helicopter environment. The effect of helicopter vibration forces on fire control instruments are of special concern to Frankford Arsenal. This has led to efforts to obtain field data on fire control instrumentation and systems during actual helicopter flights as a basis for design, production, quality assurance and general test purposes.

The process of acquiring field data through use of helicopter flights is time consuming, costly, and there are the attendant dangers associated with flight tests. This test program was designed to meet the existing need to improve testing methods and reduce costs of helicopter fire control acceptance testing by providing a means of simulating helicopter angular motion in the environmental laboratory. Angular motion measurements made in the helicopter are to be translated into environment simulation data for use with an existing untested (by Frankford Arsenal) three axis Flight Motion Simulator (FMS). The FMS will be operated throughout its capabilities, and its operational parameters will be obtained and checked to determine how well it simulates the helicopter fire control environment.

This report concerns itself with the simulation of vibration encountered by fire control instrumentation used in helicopters. The material contained in this report provides support for achieving the following objectives:

1. Provide a thorough calibration of the FMS throughout its entire range of capabilities.

2. Determine through use of pre-recorded tape data, if the FMS will duplicate helicopter motion.

3. Determine if existing specifications for fire control instrumentation for use in helicopters can be met by using the FMS.

4. Specify undesirable characteristics which can be designed out of a new improved FMS.

DESCRIPTION OF FLIGHT MOTION SIMULATOR

The Flight Motion Simulator used for this effort was designed and constructed by the Scientific System Division of Dynasciences Corporation, Blue Bell, Pa. for the U.S. Army, Frankford Arsenal. Acceptance tests were performed at the Dynasciences Corporation facilities at Blue Bell in 1970.

The FMS provides the means to subject avionics equipment in the laboratory or assembly area to angular motions in three degrees of freedom. The simulator, Figure 1, includes a hydraulically operated rate table which can be controlled in either a manual or tape mode. In manual mode, an operator can synthesize complex periodic signals. The control console contains three function generators, independently capable of providing either sine, square or triangular signals of adjustable amplitudes. Each function generator is associated with a mode control in which a single generator can drive any one, two, or all three axis simultaneously. In addition, the outputs from two or three generators may be summed to provide a complex waveform command for a single or combination of axes. In the tape mode three axes angular rates, which have sensed at a specific location on an aircraft in flight and recorded on magnetic tape, is played back through the FMS to be reproduced on the simulator table.

The major components of the FMS and their arrangement are listed below are shown in Figures 2, 3 and 4.

A. Flight Motion Table which includes:

FMS table and supporting structure;

Pitch, Roll and Yaw Activators;

Accumulator;

Accumulator Pressure Gage;

10 Micron Pressure Line Filter

B. Control Console which includes:

Function Generator #1, 2 and #3;

Mode Control Panel;

Display Control Panel with Dual Trace Oscilloscope

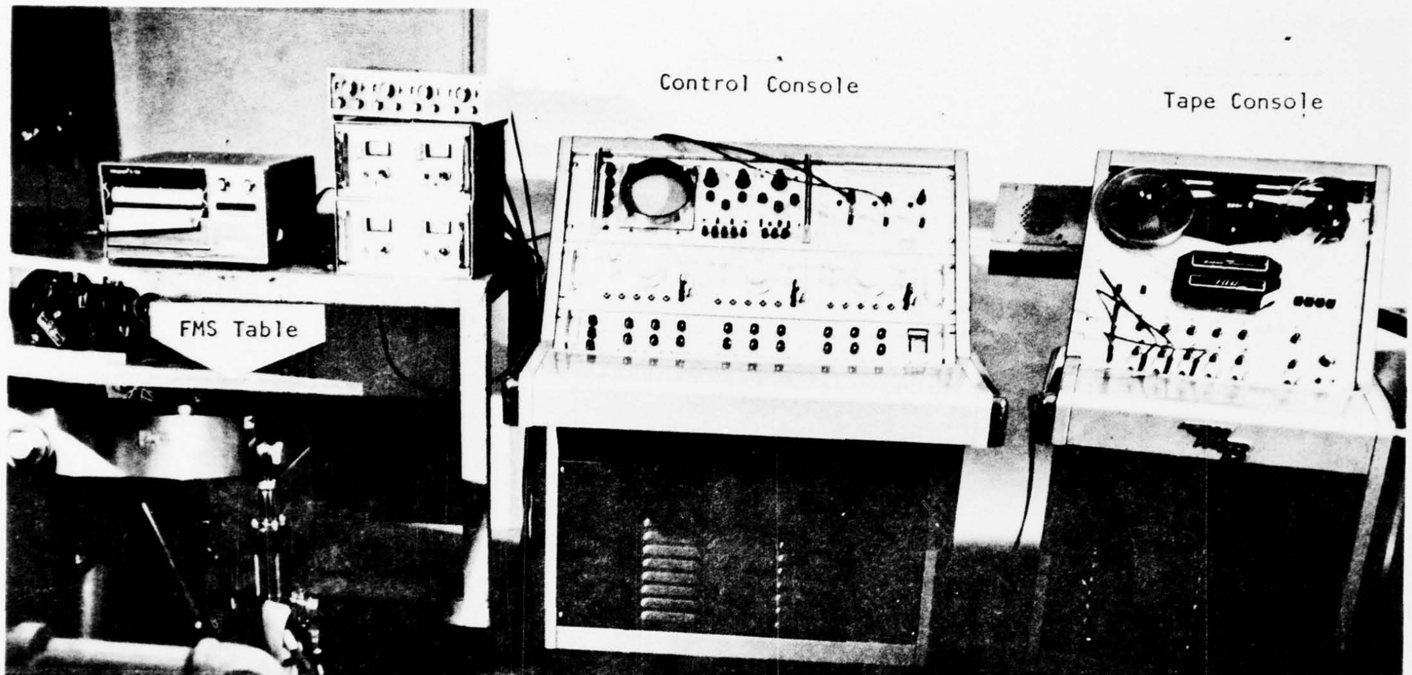


Figure 1. Flight Motion Simulator

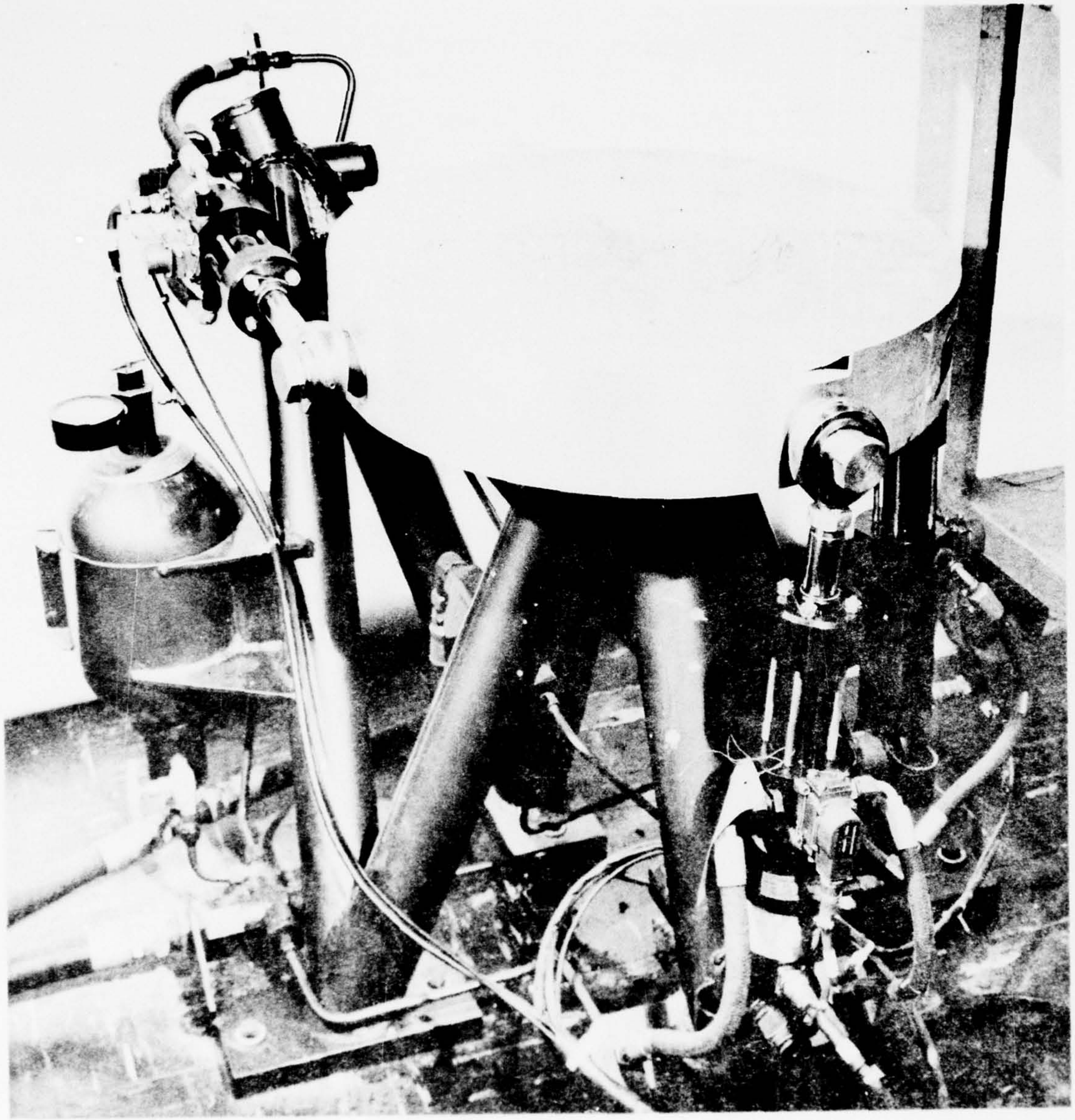


Figure 2. Flight Motion Simulator Table

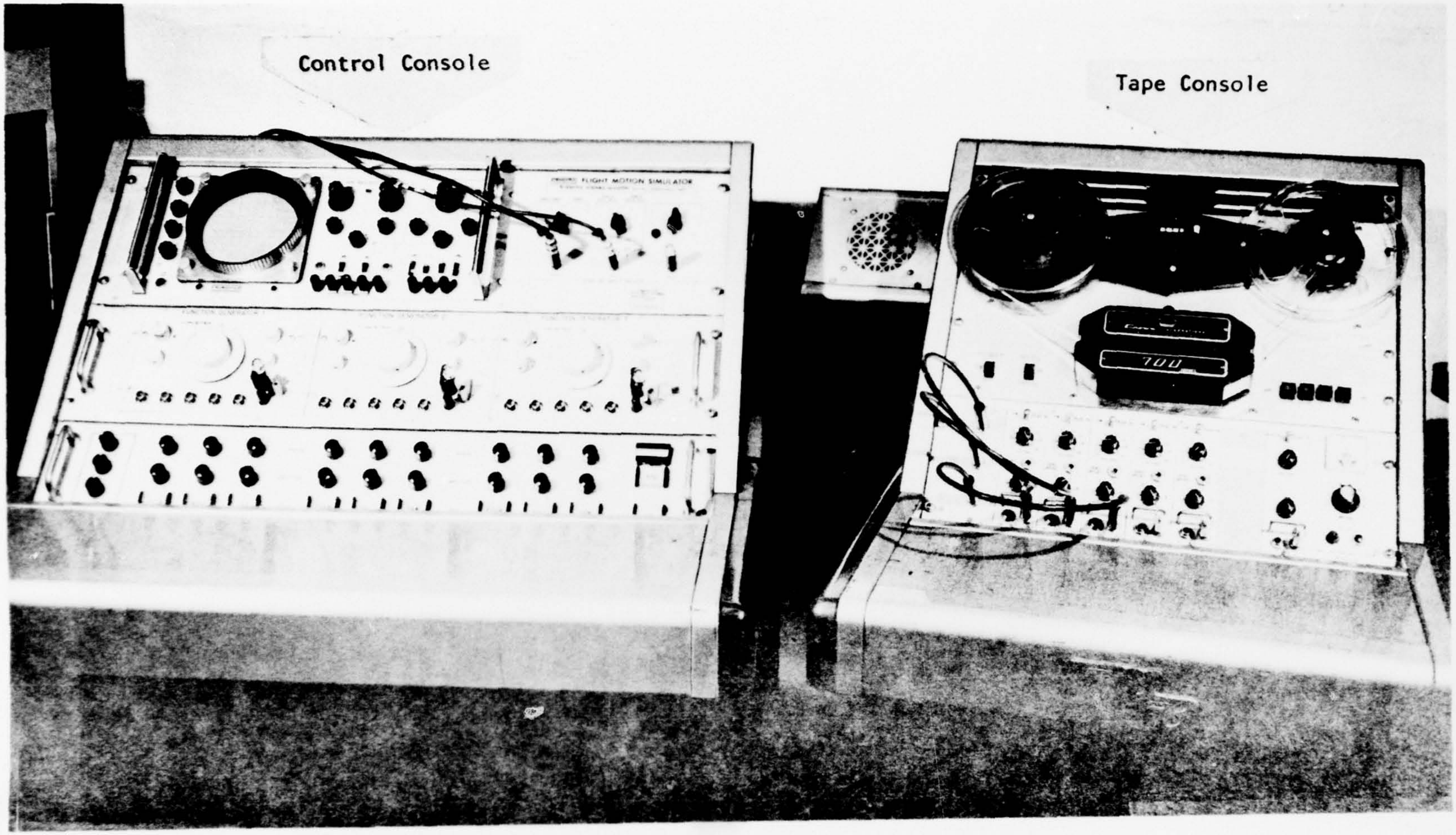


Figure 3. FMS Control Console and Tape Console

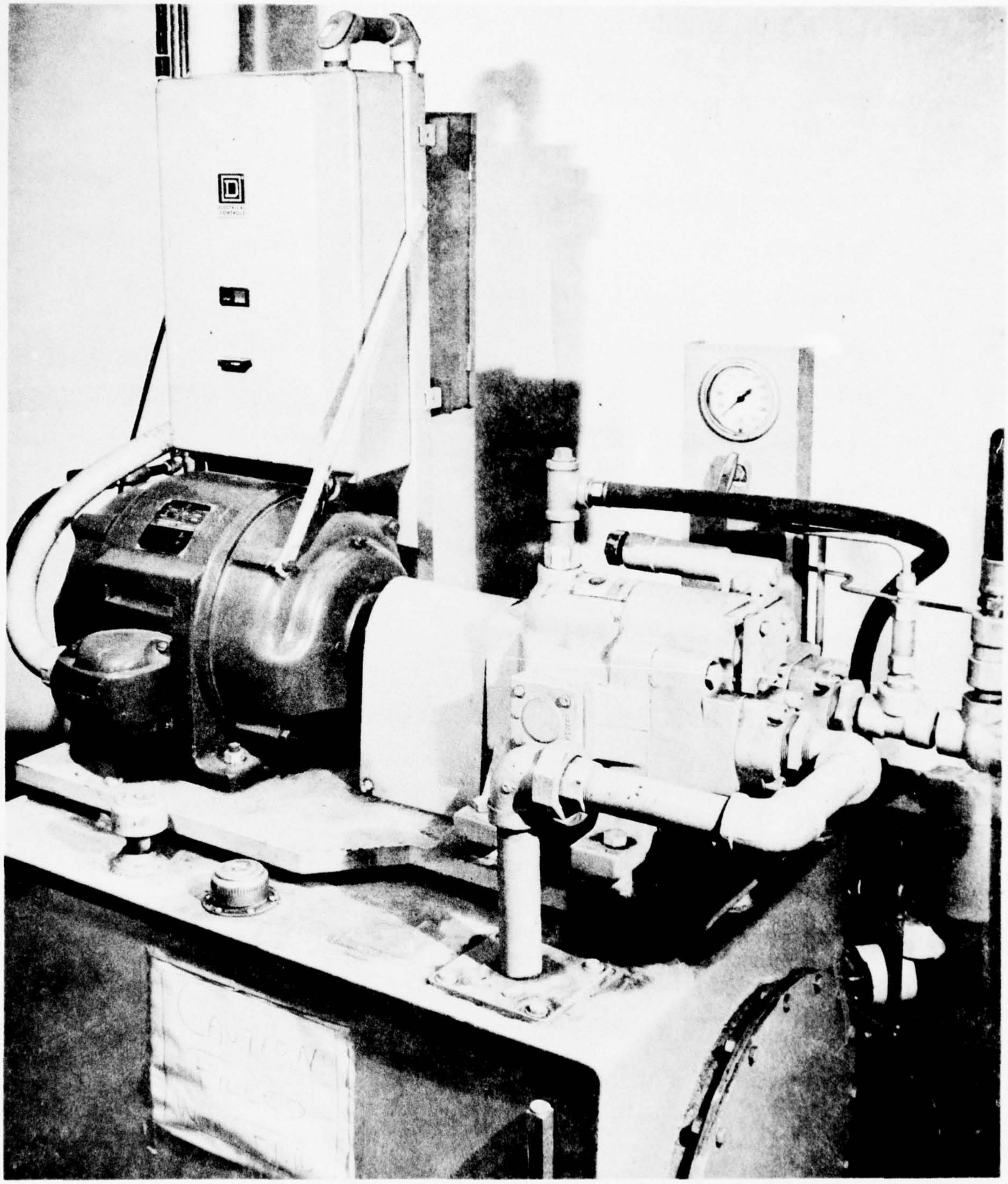


Figure 4. FMS Hydraulic Power Unit

C. Hydraulic Power Unit which includes:

Pump Motor;

Variable Displacement Pump;

Reservoir;

Pressure, Temperature, and Level Gages;

Return line cooler;

Return line filter

D. Tape Console which includes:

Tape Transport;

FM Record/Playback amplifier;

Voice track amplifier;

Patch Board for Pitch, Roll and Yaw tape signals

TEST PROGRAM AND INSTRUMENTATION

Before beginning the task of comparing the FMS's motion with that of a piece of fire control instrumentation mounted in a helicopter, we felt that, because the Simulator had been disassembled, moved from Dynasciences Laboratory to Frankford Arsenal and reassembled after its initial calibration, a recalibration was necessary to determine if any changes had occurred in the responses of the Simulator.

When the FMS was new and first placed in operation the input scale factors of the Function Generators incorporated in the simulator's electronics were as follows:

Position Cmd S.F. = 1.0 Volt/Deg. $\pm$ 5%

Table Pos R/O S.F. = 0.566 Volts/Deg. $\pm$ 5%

Table Rate R/O S.F. = 0.1 Volts/Deg. $\pm$ 5%

The recalibration showed that these function generator input scale factors had changed. They are now:

Position Cmd S.F. = 0.795 Volts/Deg. $\pm$ 5%

Table Pos R/0 S.F. = 0.450 Volts/Deg. $\pm$ 5%

Table Rate R/0 S.F. = 0.0795 Volts/Deg. $\pm$ 5%

Table 1 shows the instrumentation used in this test program.

Table 1. List of Instruments Used

ITEM	MANUFACTURING CO.	MODEL NO.
Piezoresistive Accelerometer (3)	Endevco Corp.	2262C-25
Galvanometer Amplifier	Bell & Howell	1-172A-14
Datagraph	Bell & Howell	5-134
Band-Pass Filter	Krohn-Hite	330MR
DC Power Supply	Harrison	6200B
Multifilter	General Radio	1925
Electronic Voltmeter	Bruel & Kjaer	2425
Oscilloscope	Tektronix	454
Power Supply	Endevco	7403

To obtain these new scale factors the following calibration procedure from the operating instructions of the FMS was used.

Step 1 - The FMS's power and hydraulics were turned on and the Pitch, Roll and Yaw commands were adjusted to $0^V \pm 0.02^V$ with the Pitch, Roll and Yaw centering controls located on the control console.

Step 2 - Measure and record the:

(a) Pitch Table Position R/0 in volts, A_1

(b) Pitch Actuator Displacement, in inches, B_1

Step 3 - Change Pitch Table Command to $5.0^V \pm 1\%$ with the Pitch Centering Control.

Step 4 - Measure the Pitch Actuator Displacement. It should read:

B_1 + 0.960 inches $\pm$ .01

If not, adjust potentiometer Rg on the pitch servo P.C. card until the Pitch Actuator displacement is within the desired range.

Step 5 - Measure the Pitch Table Position Read-out, in volts, A_2
The Pitch Table Position Scale Factor is computed from:

$$\text{Table Position R/0 S.F.} = \frac{A_2 - A_1}{5}$$

After the Position R/0 S.F. has been calculated the input voltage to the FMS is adjusted until this calculated value can be read at the Position R.O. terminal on the control console. The Table Position Command voltage and Table Rate R/0 voltage can then be measured at their respective read out points on the control console.

Steps 2 through 5 are repeated for the Roll and Yaw axes.

EVALUATION PROCEDURE - PHASE 1

Having established these new parameters, it was possible to proceed to the first step of calibrating the FMS through its entire range of capabilities. To determine linearity of the machine, the FMS vibration table was positioned so that the Actuator Displacement, in inches, was zero. The input, in volts, to the table position command was varied until the Actuator had been displaced to maximum in both the positive and negative positions. Each time the Table Position Command voltage was changed the Table Position R/0 voltage and the Table Position Actuator Displacement, in inches, was recorded. This data is shown on Data Sheets 1, 2 and 3. Using this data the linearity plots shown in Figures 5, 6 and 7 were made.

Data Sheet #1. Flight Motion Simulator Test Data Sheet for Linearity Plot - Yaw Axis

CONTROL AXIS	TABLE POSITION COMMAND (VOLTS)	TABLE POSITION R/O (VOLTS)	TABLE POSITION ACTUATOR DISPLACEMENT (IN.)
Yaw Axis	+ .03	+ .41	0
	+ 1.0	+ .16	+ .2
	+ 2.0	- .75	+ .5
	+ 3.0	- 1.31	+ .75
	+ 4.0	- 1.87	+ 1.0
	+ 5.0	- 2.48	+ 1.25
	+ 6.0	- 2.98	+ 1.5
	+ 7.0	- 3.55	+ 1.7
	+ 8.0	- 4.15	+ 2.0
	+ 9.0	- 4.68	+ 2.2
	- 1.0	+ .95	- .25
	- 2.0	+ 1.51	- .5
	- 3.0	+ 2.11	- .7
	- 4.0	+ 2.66	- .9
	- 5.0	+ 3.24	- 1.2
	- 6.0	+ 3.81	- 1.5
	- 7.0	+ 4.37	- 1.7
	- 8.0	+ 4.95	- 2.1

Data Sheet #2. Flight Motion Simulator Test Data Sheet
For Linearity Plot - Roll Axis

CONTROL AXIS	TABLE POSITION COMMAND (VOLTS)	TABLE POSITION R/O (VOLTS)	TABLE POSITION ACTUATOR DISPLACEMENT (IN.)
Roll Axis	+ .12	- .18	0
	+ 1.12	- .81	+ .2
	+ 2.12	- 1.42	+ .4
	+ 3.12	- 1.99	+ .6
	+ 4.12	- 2.60	+ .8
	+ 5.12	- 3.22	+ 1.0
	+ 6.12	- 3.83	+ 1.25
	+ 7.12	- 4.42	+ 1.45
	+ 8.12	- 5.04	+ 1.7
	- 1.12	+ .54	- .3
	- 2.12	+ 1.12	- .5
	- 3.12	+ 1.72	- .7
	- 4.12	+ 2.34	- .9
	- 5.12	+ 2.94	- 1.1
	- 6.12	+ 3.54	- 1.35
	- 7.12	+ 4.12	- 1.55
	- 8.12	+ 4.74	- 1.85
	- 9.00	+ 5.23	- 2.1

Data Sheet #3. Flight Motion Simulator Test Data Sheet
For Linearity Plot - Pitch Axis

CONTROL AXIS	TABLE POSITION COMMAND (VOLTS)	TABLE POSITION R/O (VOLTS)	TABLE POSITION ACTUATOR DISPLACEMENT (IN.)
Pitch Axis	- 2.00	+ 1.10	0
	- 1.00	+ .55	.2
	0	- .05	.4
	+ 1.0	- .60	.6
	+ 2.0	- 1.19	.8
	+ 3.0	- 1.77	1.0
	+ 4.0	- 2.37	1.2
	+ 5.0	- 2.92	1.4
	+ 6.0	- 3.52	1.6
	+ 7.0	- 4.10	1.8
	- 3.0	+ 1.69	- .2
	- 4.0	- 2.30	- .4
	- 5.0	+ 2.88	- .6
	- 6.0	+ 3.44	- .8
	- 7.0	+ 4.04	- 1.0
	- 8.0	+ 4.62	- 1.2
	- 8.5	+ 4.92	- 1.5

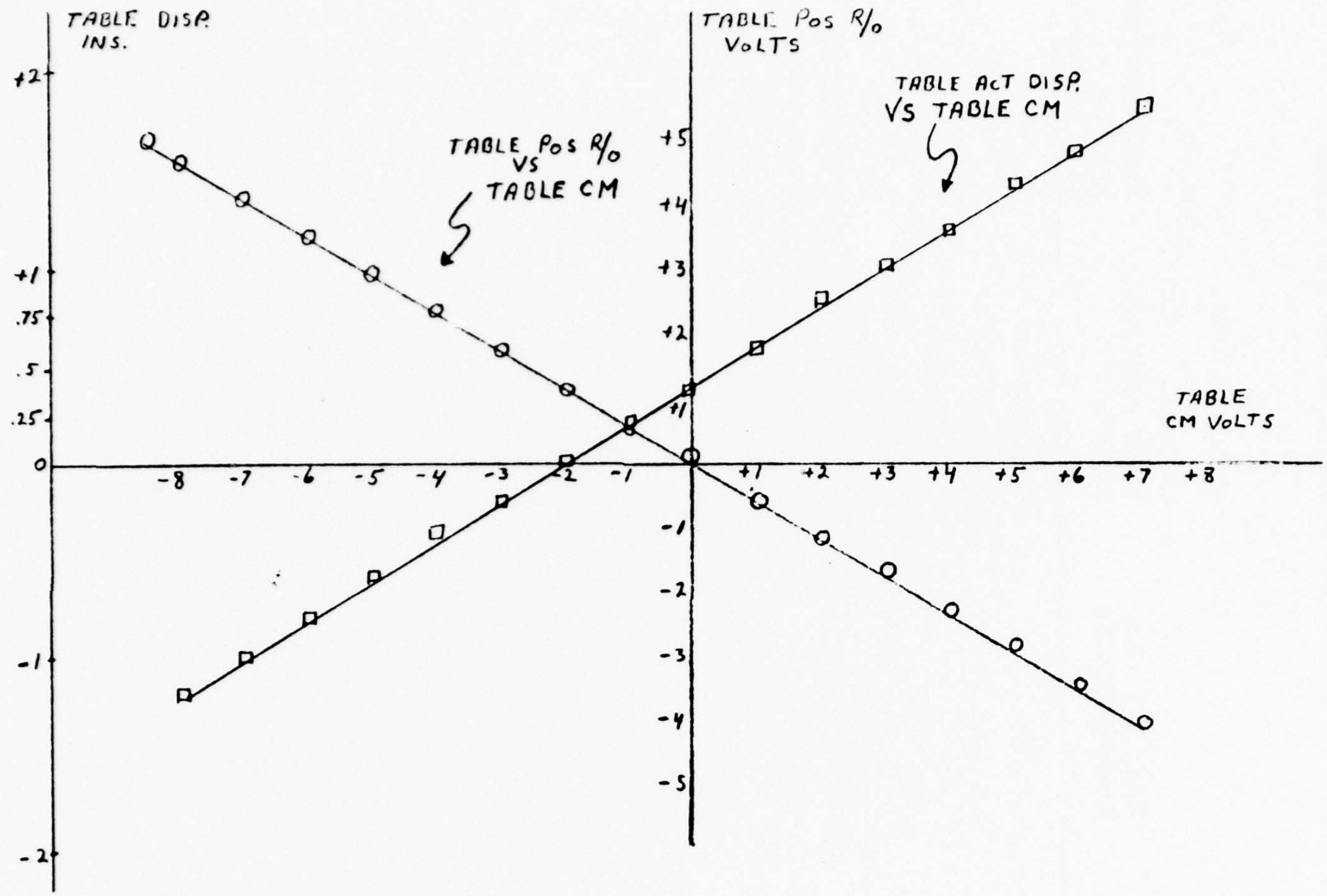


Figure 5. Pitch Axis Linearity Plot

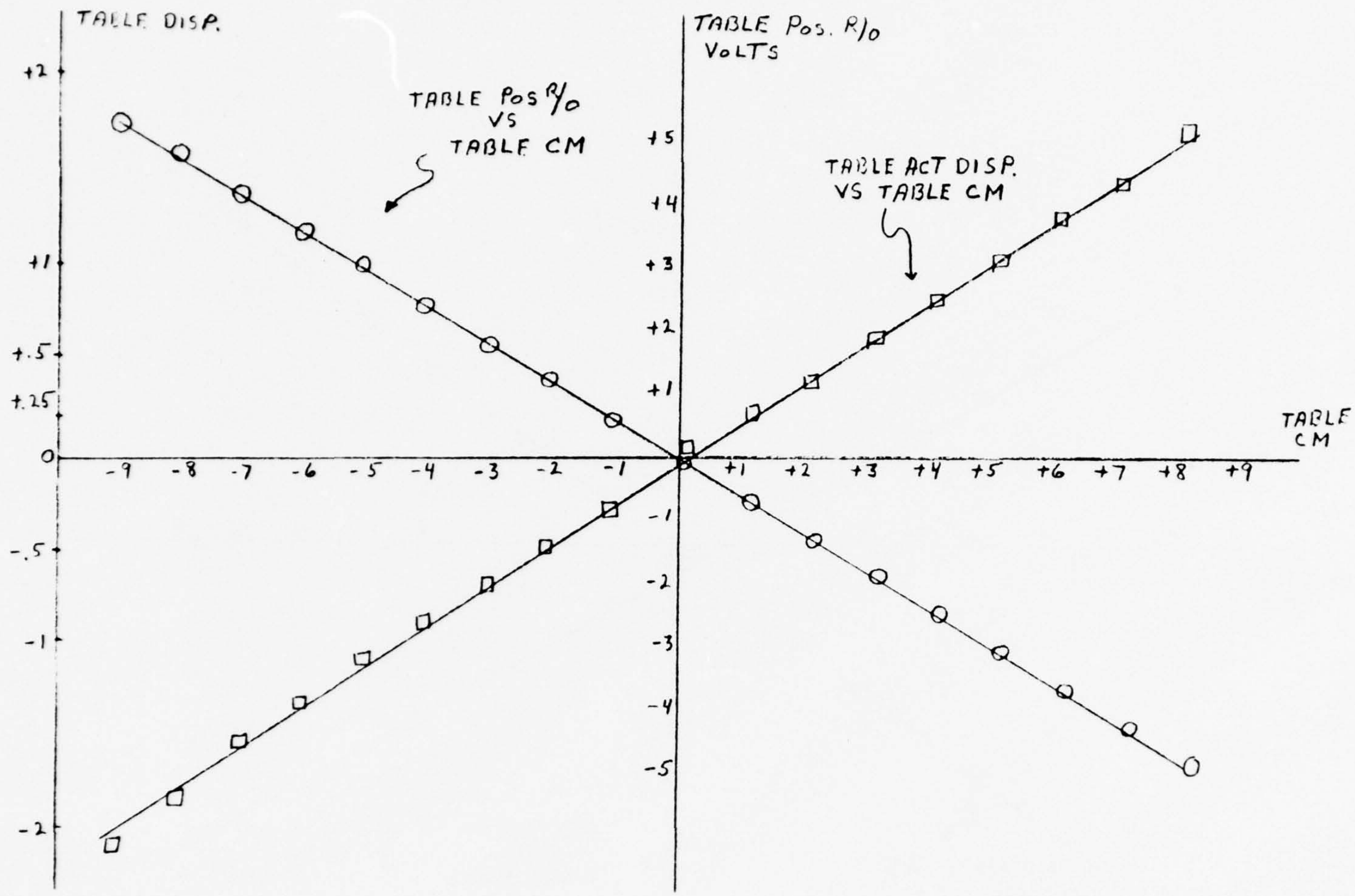


Figure 6. Roll Axis Linearity Plot

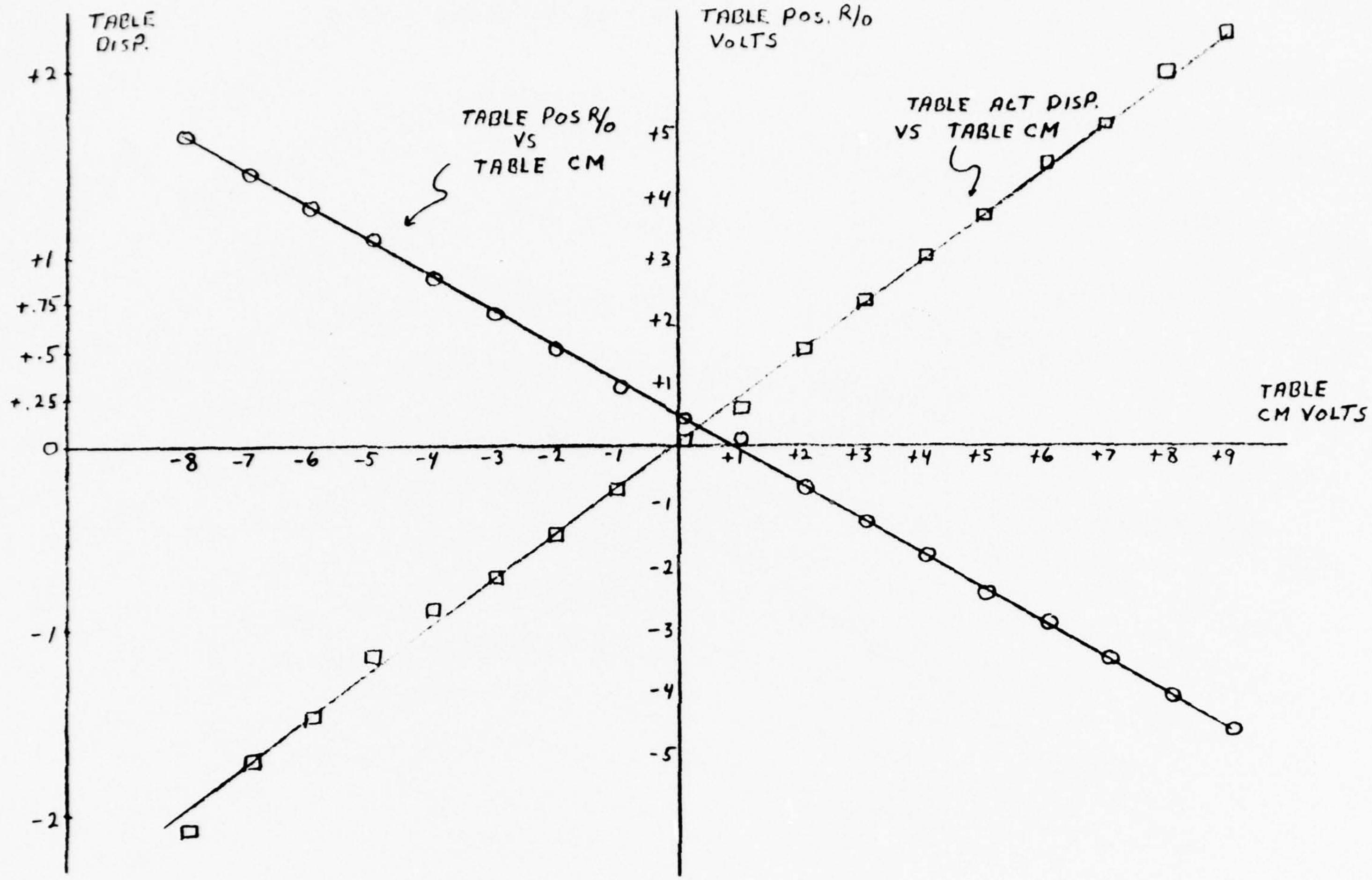


Figure 7. Yaw Axis Linearity Plot

To determine the frequency response of the FMS, the simulator was operated by applying a constant input voltage to the table command while varying the operating frequency through the range of from one to sixty Hertz. By using the instrumentation set-up as shown in Figure 8 for manual input and Figure 9 for tape input, the output of the FMS vibration table was monitored by the use of three Endevco Model 2262-25 Piezoresistive Accelerometers, one mounted on each axis, Pitch, Roll and Yaw. The output voltages of the accelerometers were converted to g's and from the g values, linear displacement and linear velocity were calculated using the equations:

1) $$\text{g's (pk)} = \frac{(V_a)\quad(\sqrt{2})}{0.25}$$

Where V_a = accelerometer output rms voltage

0.25 = accelerometer sensitivity in volts/g

2) Linear Displacement (d)

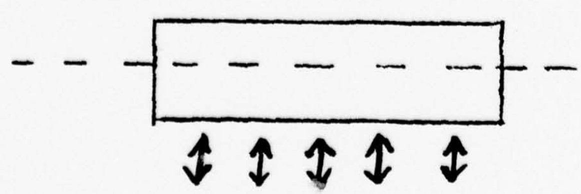
$$d = 9.780 \frac{G}{f^2} \text{ inches pk.}$$

3) Linear Velocity (v)

$$v = 61.4 \frac{G}{F} \text{ in./sec. pk.}$$

Since Fire Control instrumentation mounted in helicopters is subjected to angular motions in three planes (Pitch, Roll and Yaw), see Figure 10, we felt that data in angular terms would be of more value to the Fire Control engineer.

Angular motion differs from linear motion in that in linear motion the motion is applied uniformly along the body receiving the motion:



Linear Motion

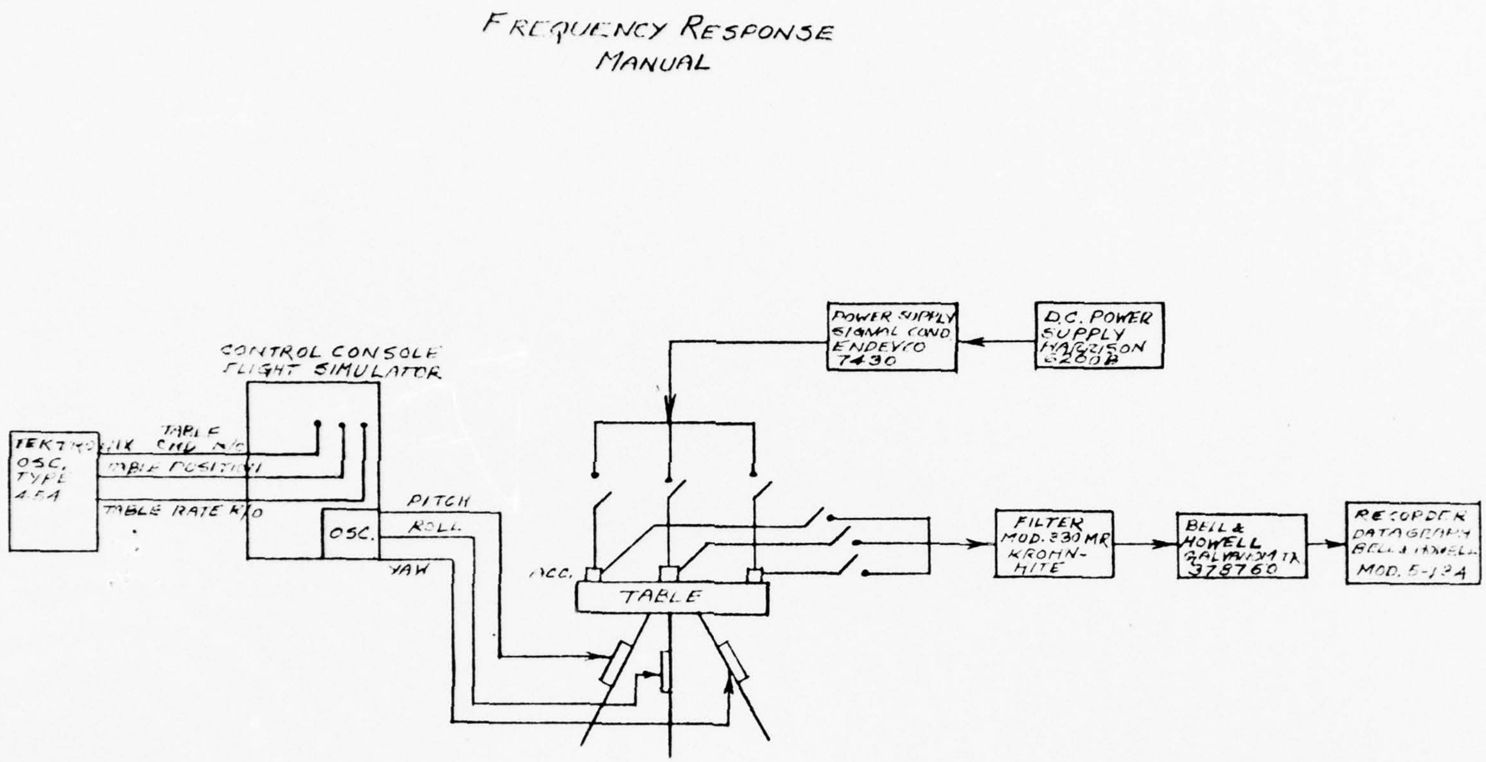


Figure 8. Test Instrumentation for Manual Operation

USING THE MULTIFILTER
Going into the Tape Input

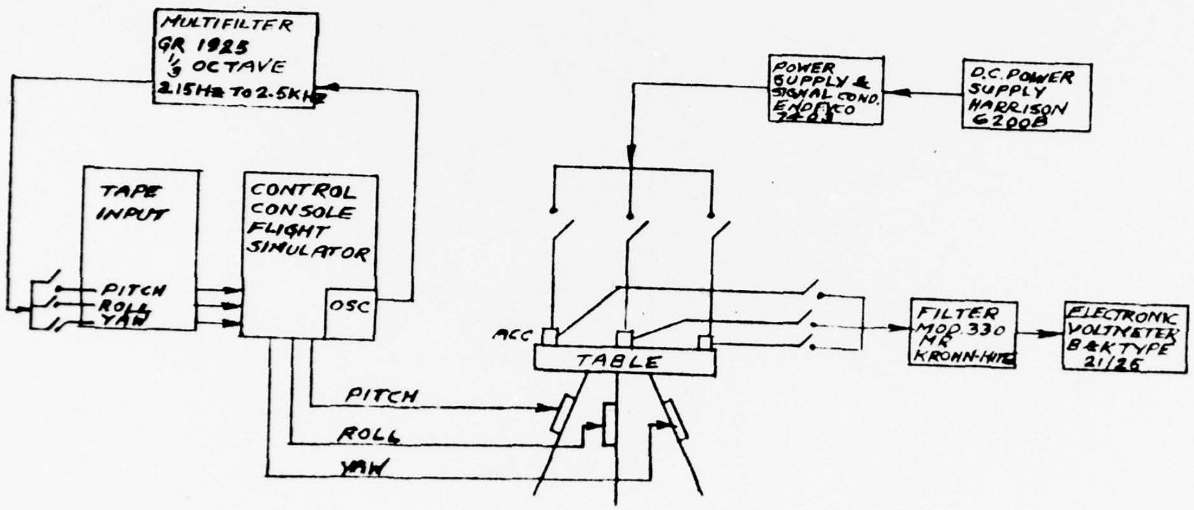


Figure 9. Test Instrumentation for Operation using Tape Input

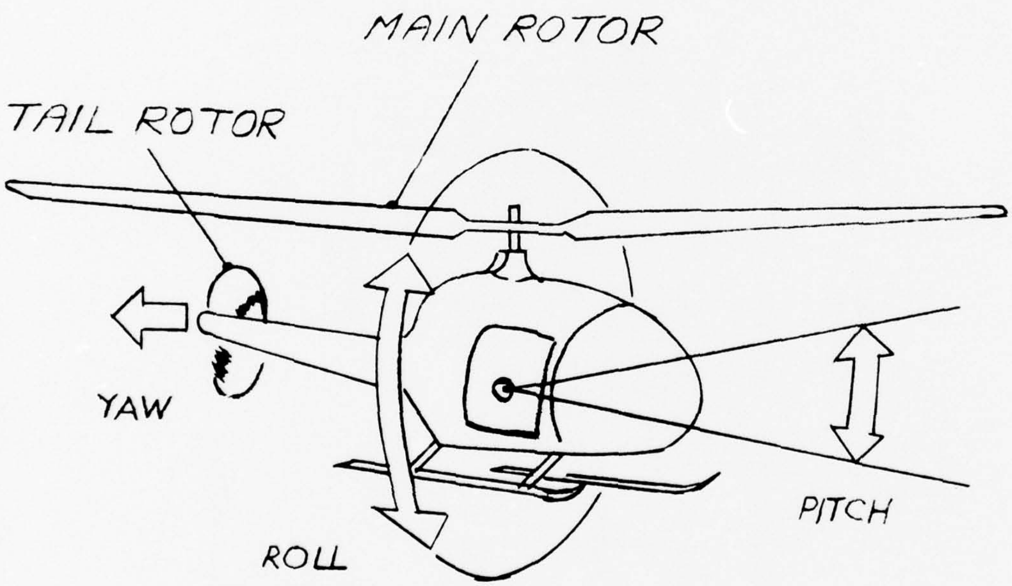
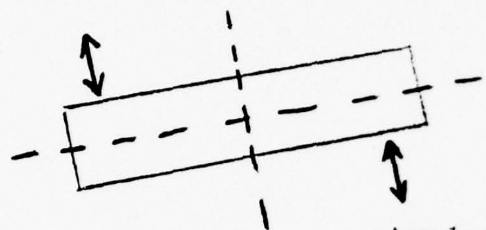


Figure 10. Angular Motions of a Helicopter

whereas in angular motion the body receiving the motion tends to oscillate around an axis:



From the linear values already calculated, the angular values of displacement, velocity and acceleration, were calculated using the equations:

1) Angular Displacement = θ

$$\theta = \frac{\text{Linear Displacement}}{10} \text{ rad. X } \frac{360}{2\pi} = \text{deg.}$$

2) Angular Velocity = $\dot{\theta}$

$$\dot{\theta} = \frac{\text{Linear Velocity}}{10} \text{ rad./sec. X } \frac{360}{2\pi} = \text{deg./sec.}$$

3) Angular Acceleration = $\ddot{\theta}$

$$\ddot{\theta} = \frac{\text{Linear Acceleration}}{10} \text{ rad/sec.}^2 \text{ X } \frac{360}{2\pi} = \text{deg./sec.}^2$$

where:

10 is the length of the radius, in inches

Using this procedure, enough data was obtained to plot a series of curves depicting the output characteristics of the machine while being operated in:

a. The manual mode, Figures 11-19

b. The tape mode, Figures 20-28

c. The tape mode with a shaping network in the FMS's input circuit Figures 29-37.

Figure 11. Pitch Axis, Angular Acceleration, Manual Input, No Load on the Table. Input .707 VRMS

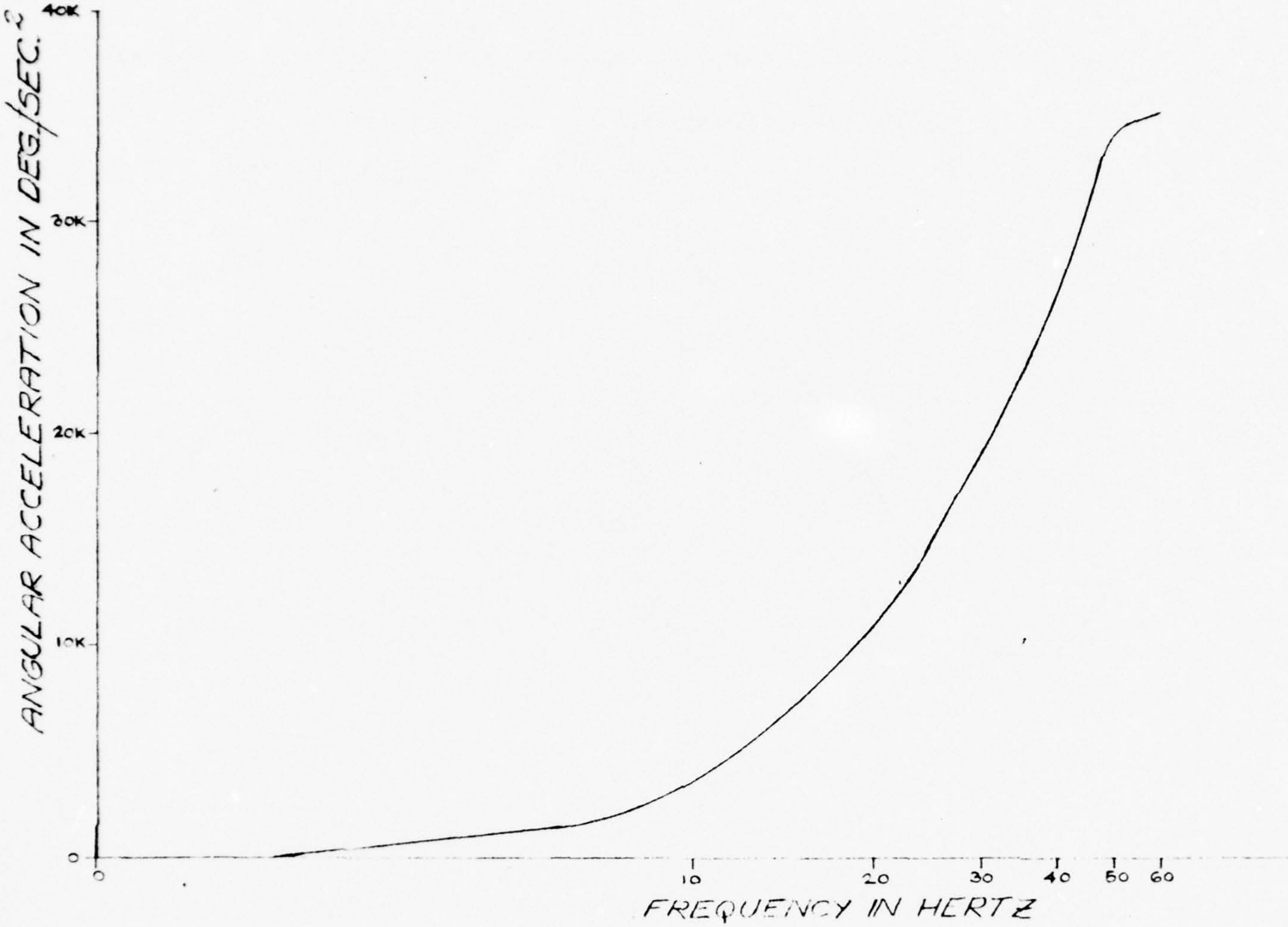


Figure 12. Roll Axis, Angular Acceleration, Manual Input, No Load on the Table, Input .707 VRMS

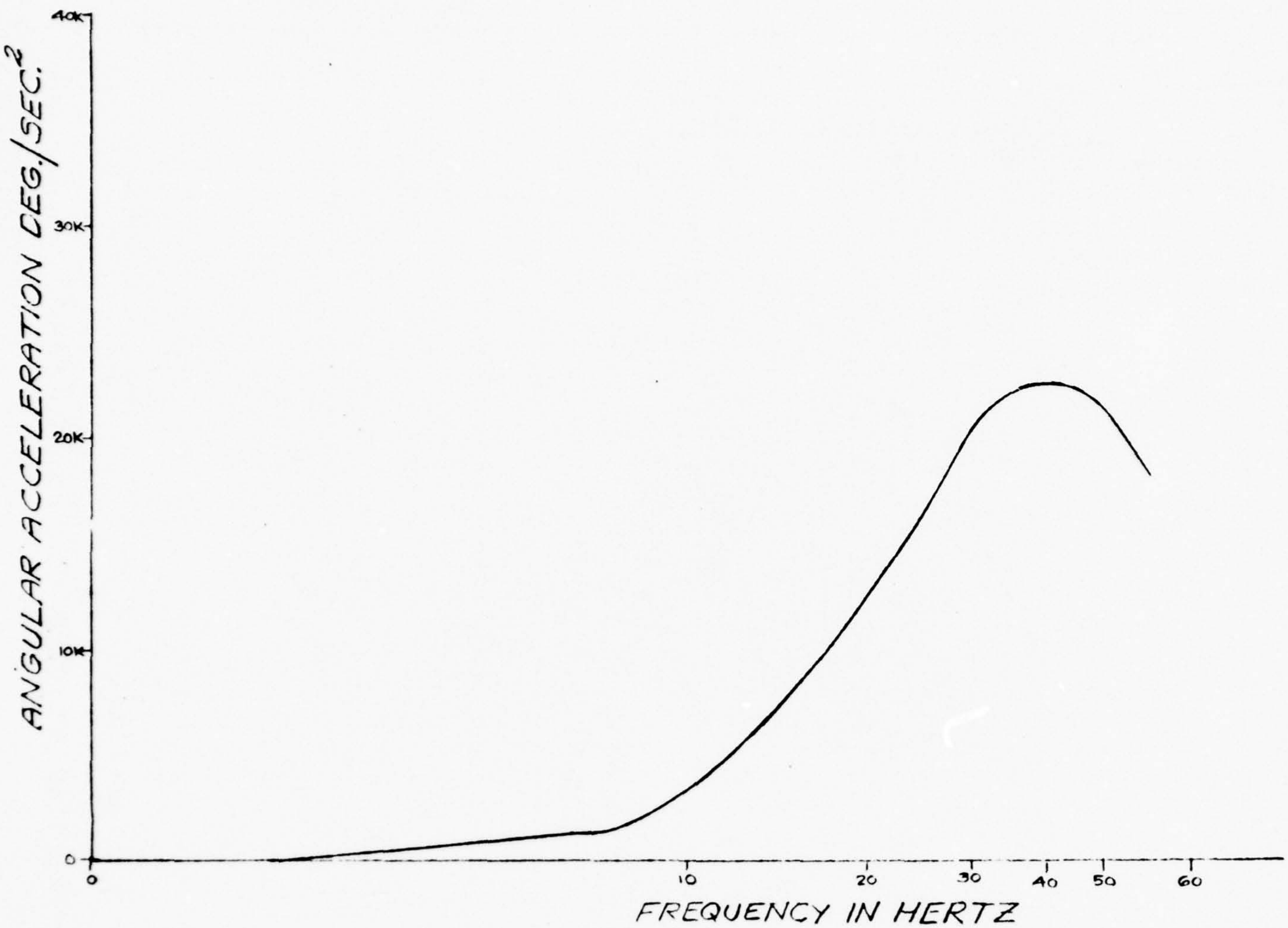


Figure 13. Yaw Axis, Angular Acceleration, Manual Input, No Load on Table, Input .707 VRMS

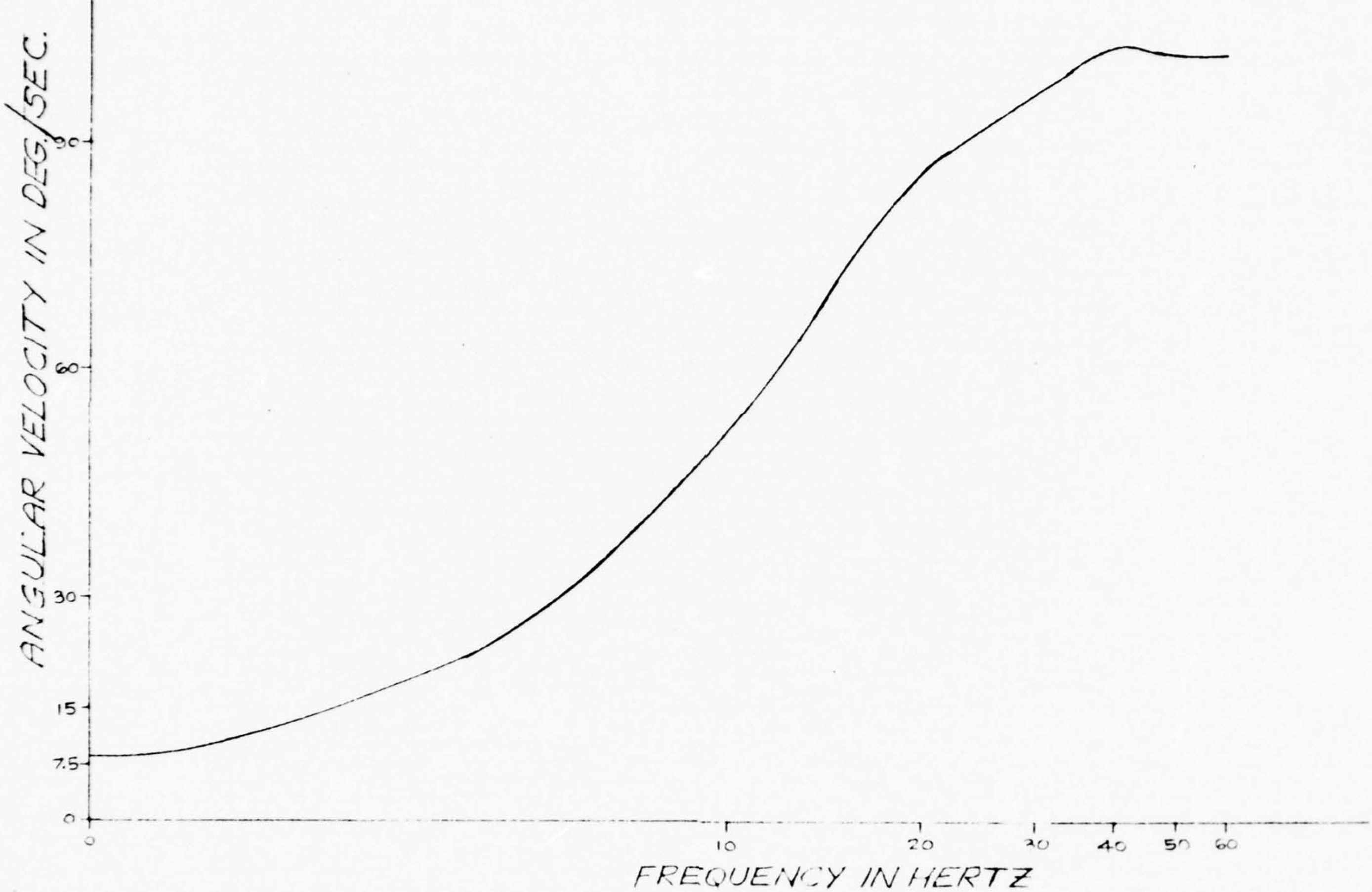


Figure 14. Pitch Axis, Angular Velocity, Manual Input, No Load on the Table, Input .707 VRMS

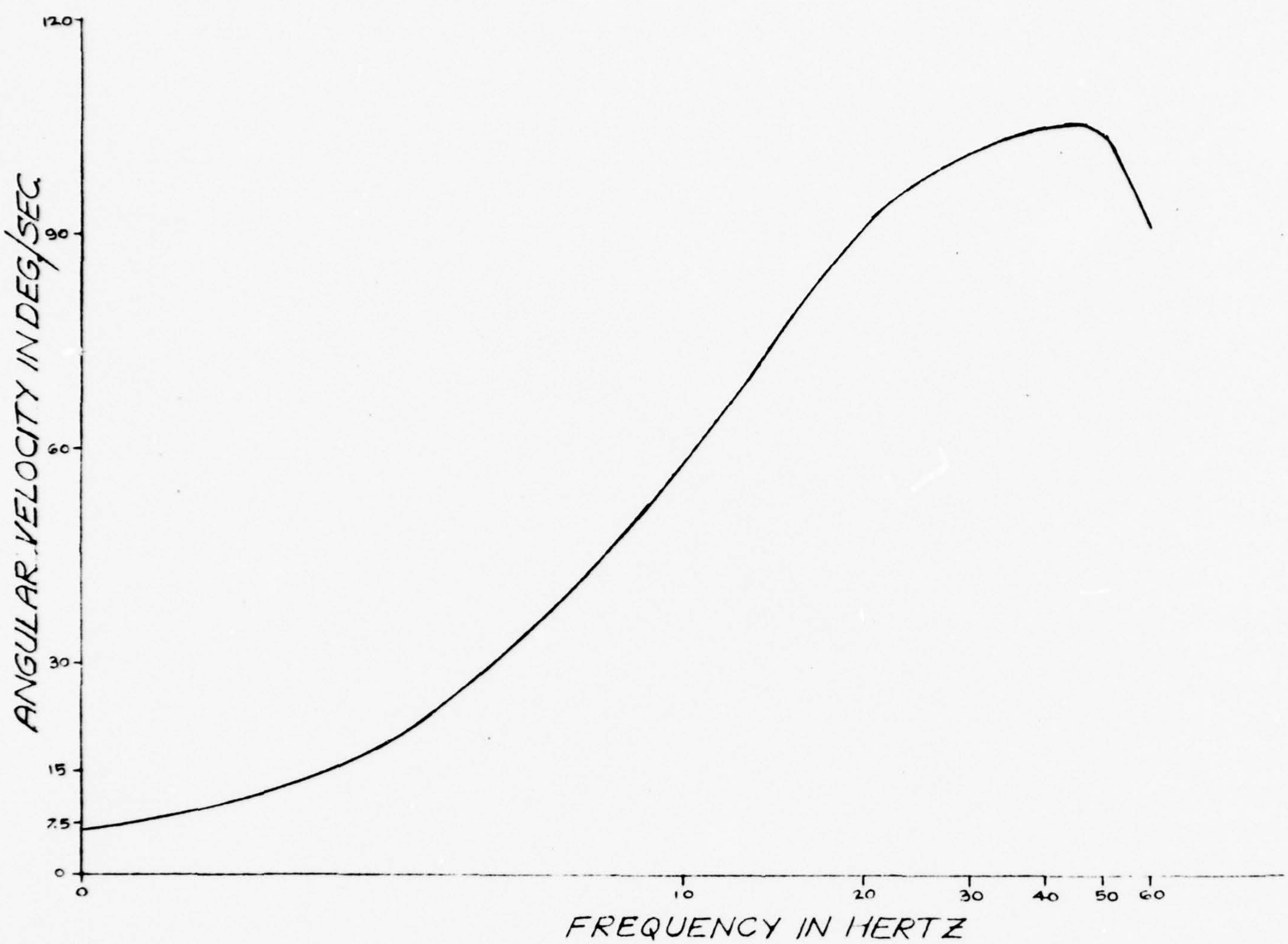


Figure 15. Roll Axis, Angular Velocity, Manual Input, No Load on the Table, Input .707 VRMS

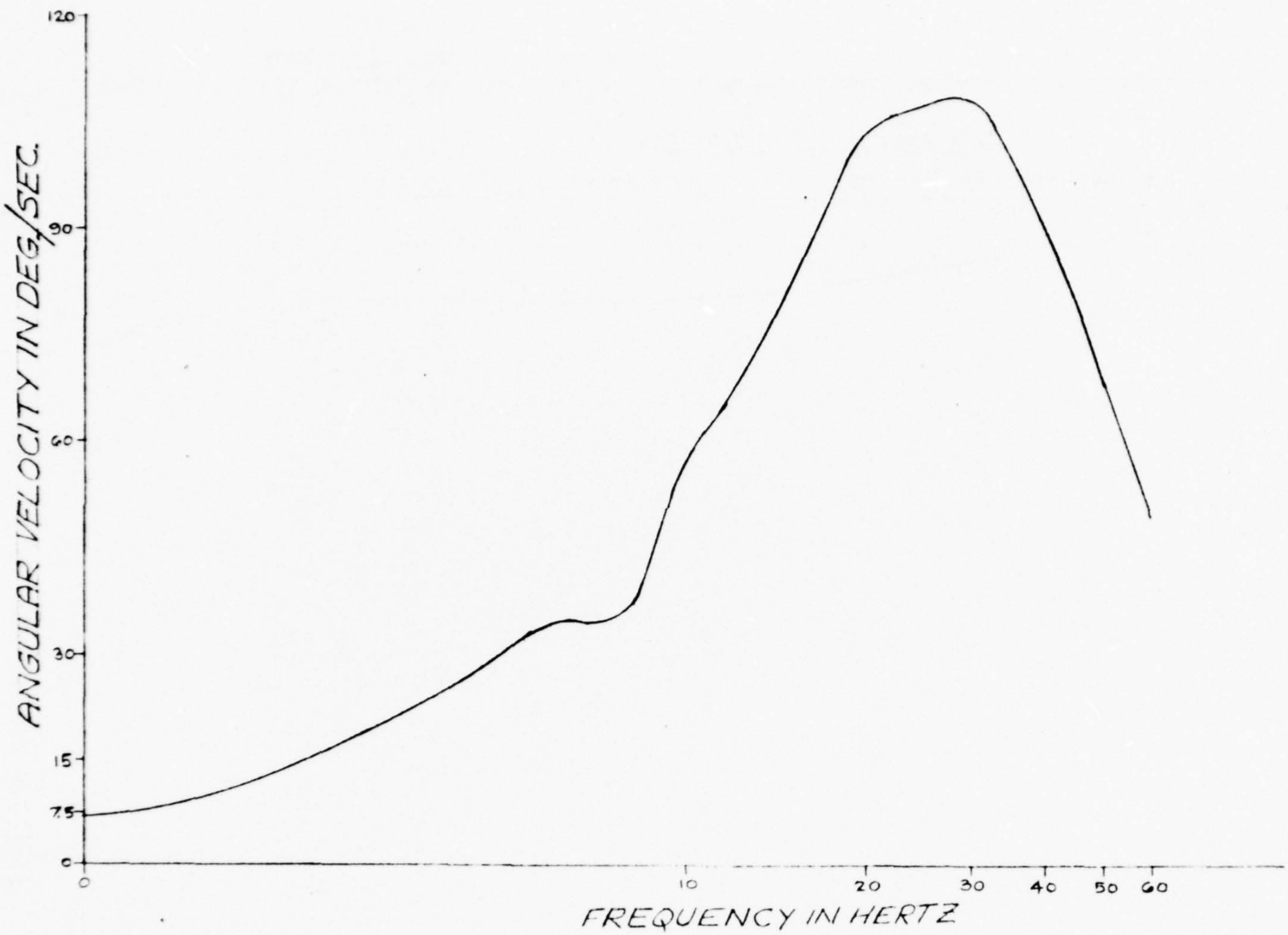


Figure 16. Yaw Axis, Angular Velocity, Manual Input, No Load on the Table, Input .707 VRMS

Figure 17. Pitch Axis, Angular Displacement, Manual Input, No Load on the Table, Input .707 VRMS

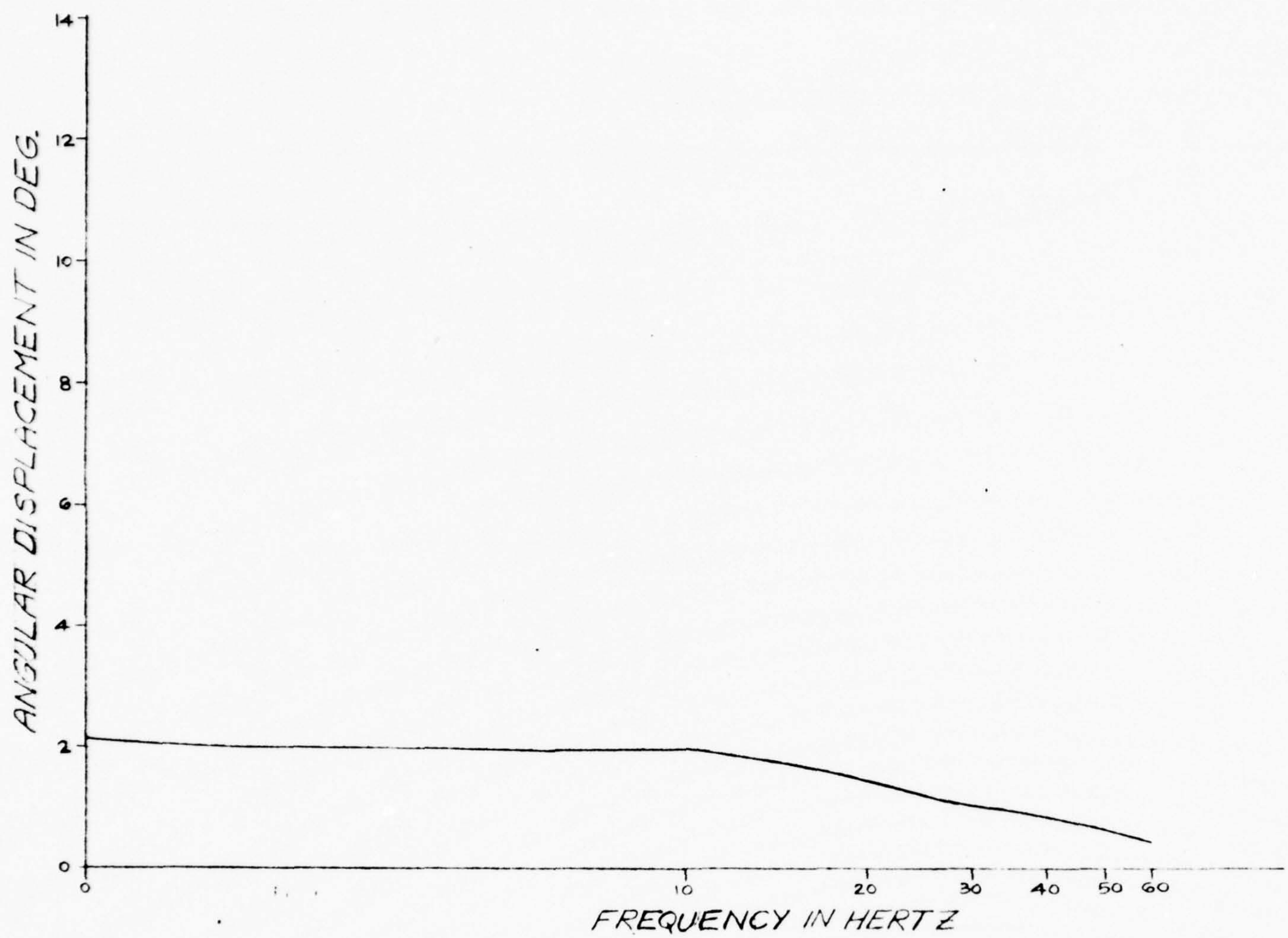


Figure 18. Roll Axis, Angular Displacement, Manual Input, No Load on the Table, Input, .707 Axis

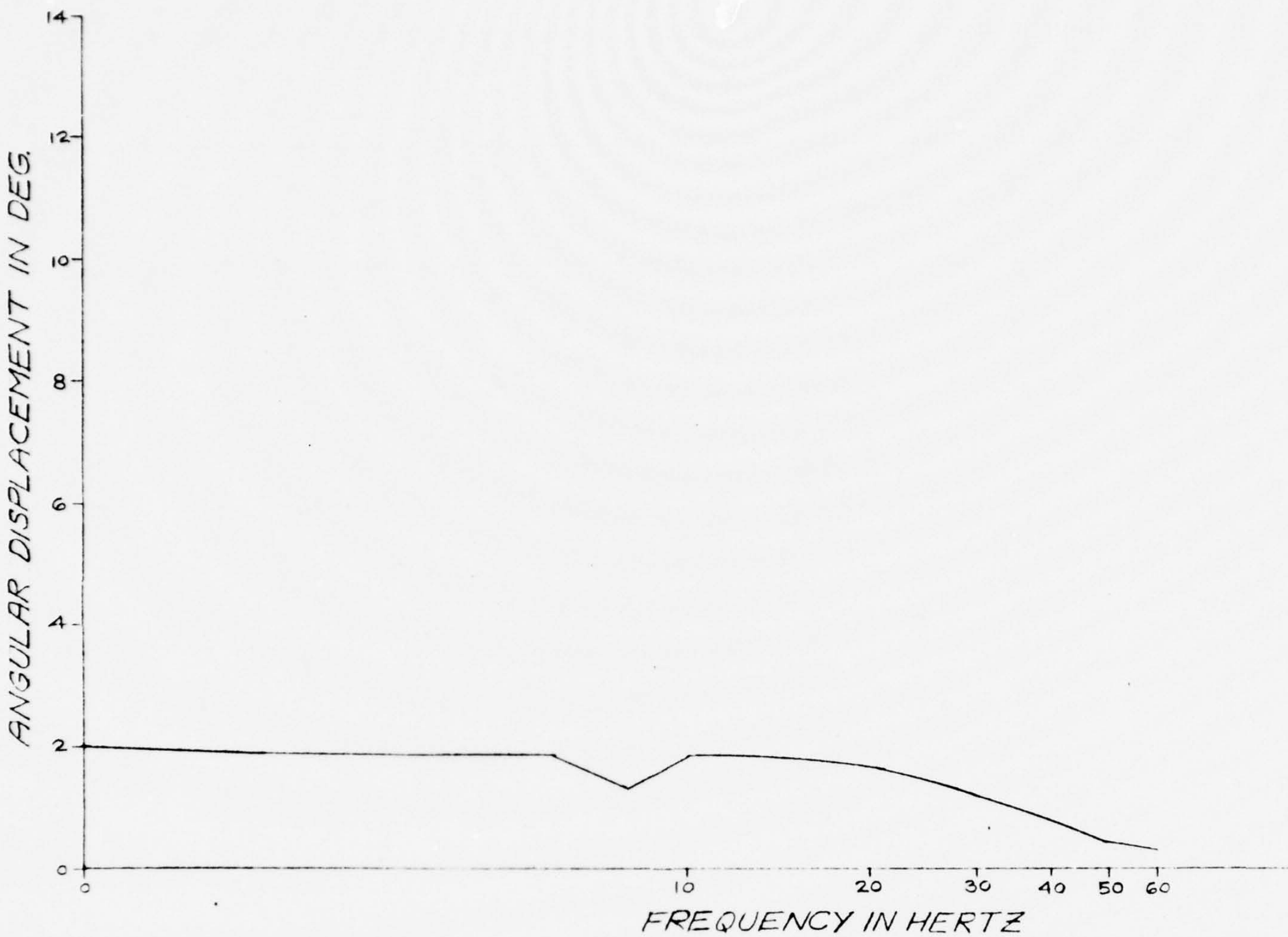


Figure 19. Yaw Axis, Angular Displacement, Manual Input, No Load on the Table, Input .707 VRMS

Figure 20. Pitch Axis, Angular Acceleration, Tape Input, No Load on the Table, Input .707 VRMS

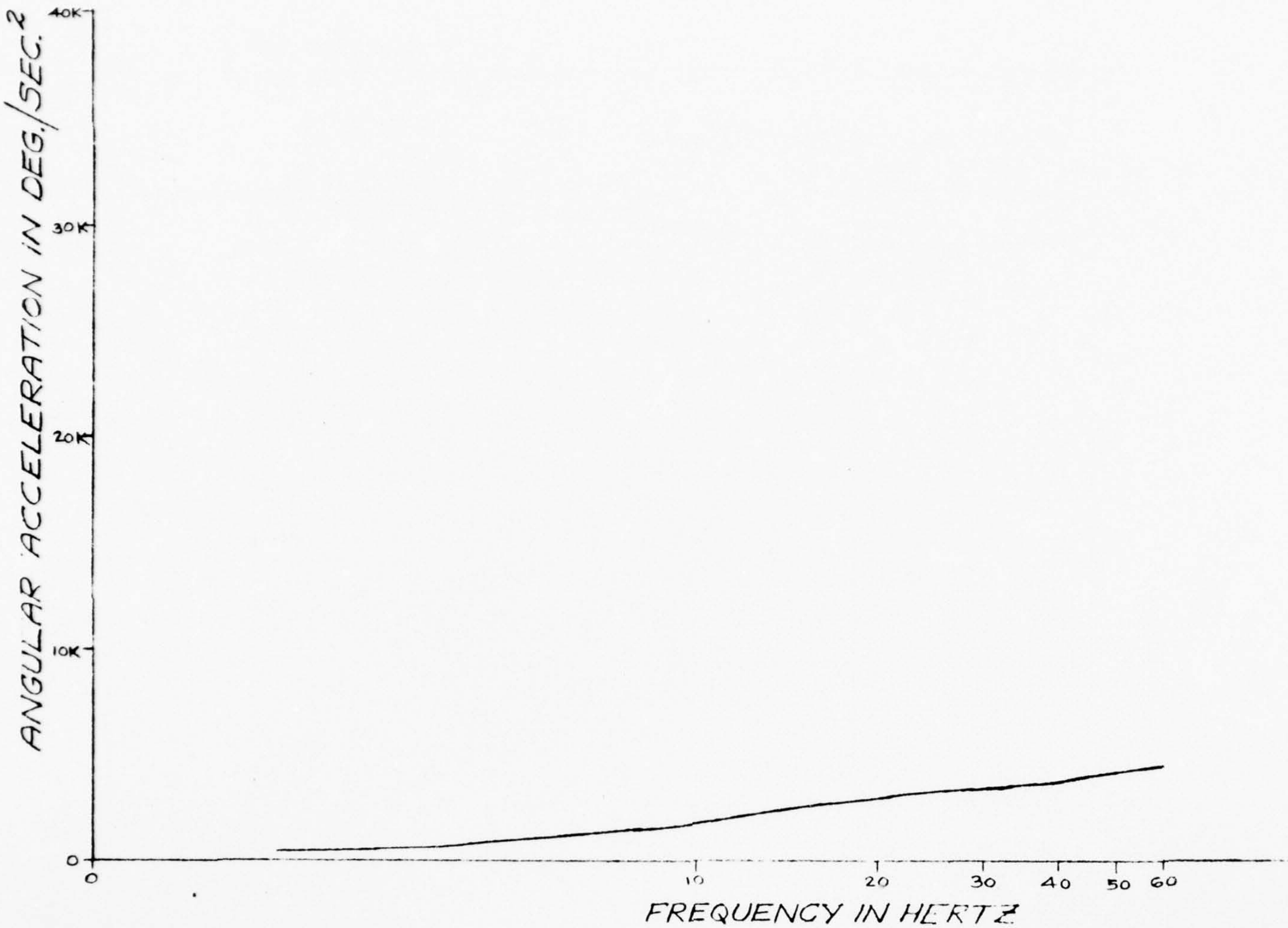


Figure 21. Roll Axis, Angular Acceleration, Tape Input, No Load on the Table, Input .707 VRMS

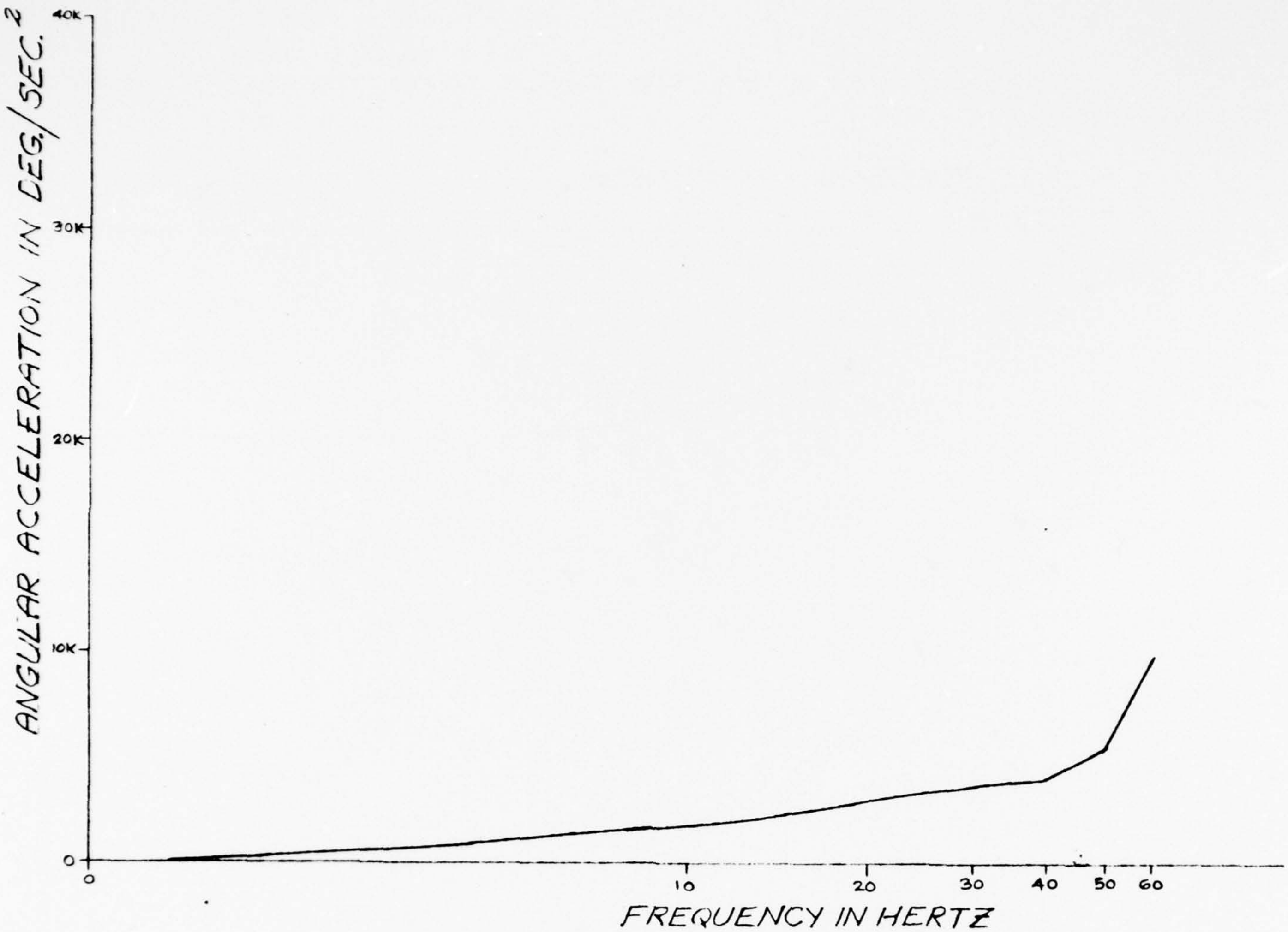


Figure 22. Yaw Axis, Angular Acceleration, Tape Input, No Load on the Table, Input .707 VRMS

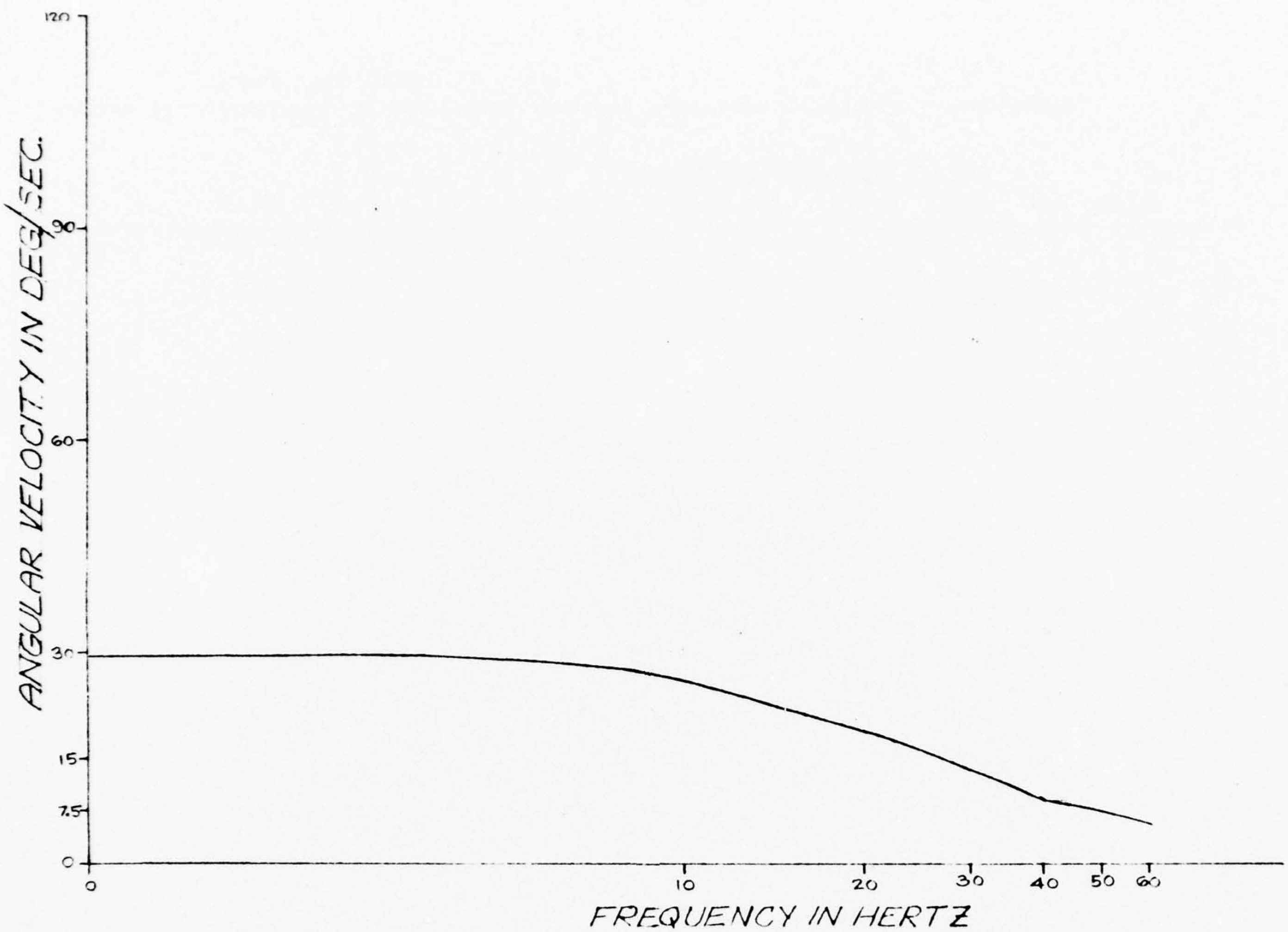


Figure 23. Pitch Axis, Angular Velocity, Tape Input, No Load on the Table, Input .707 VRMS

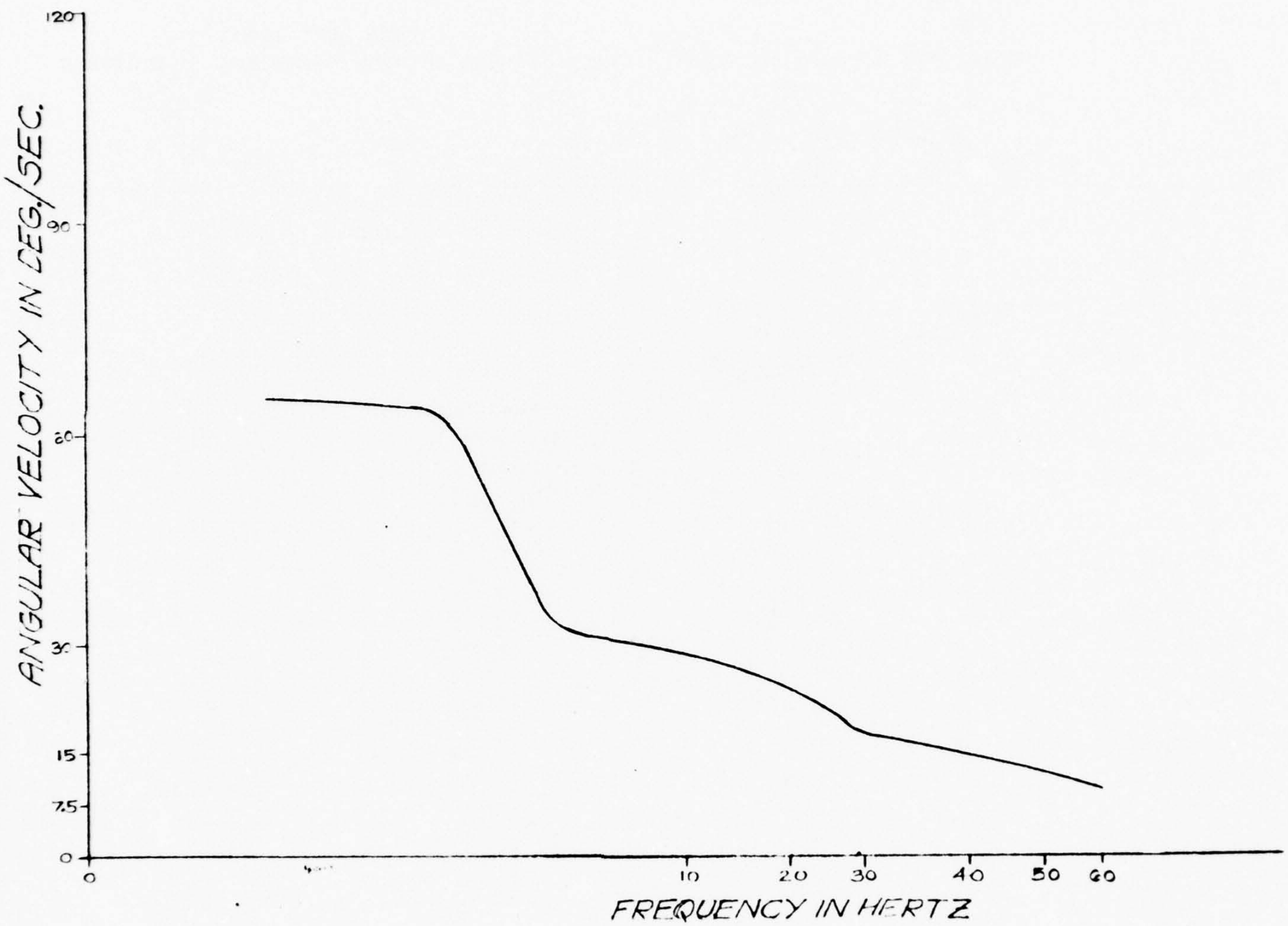


Figure 24. Roll Axis, Angular Velocity, Tape Input, No Load on the Table. Input .707 VRMS

Figure 25. Yaw Axis, Angular Velocity, Tape Input, No Load on the Table, Input .707 VRMS

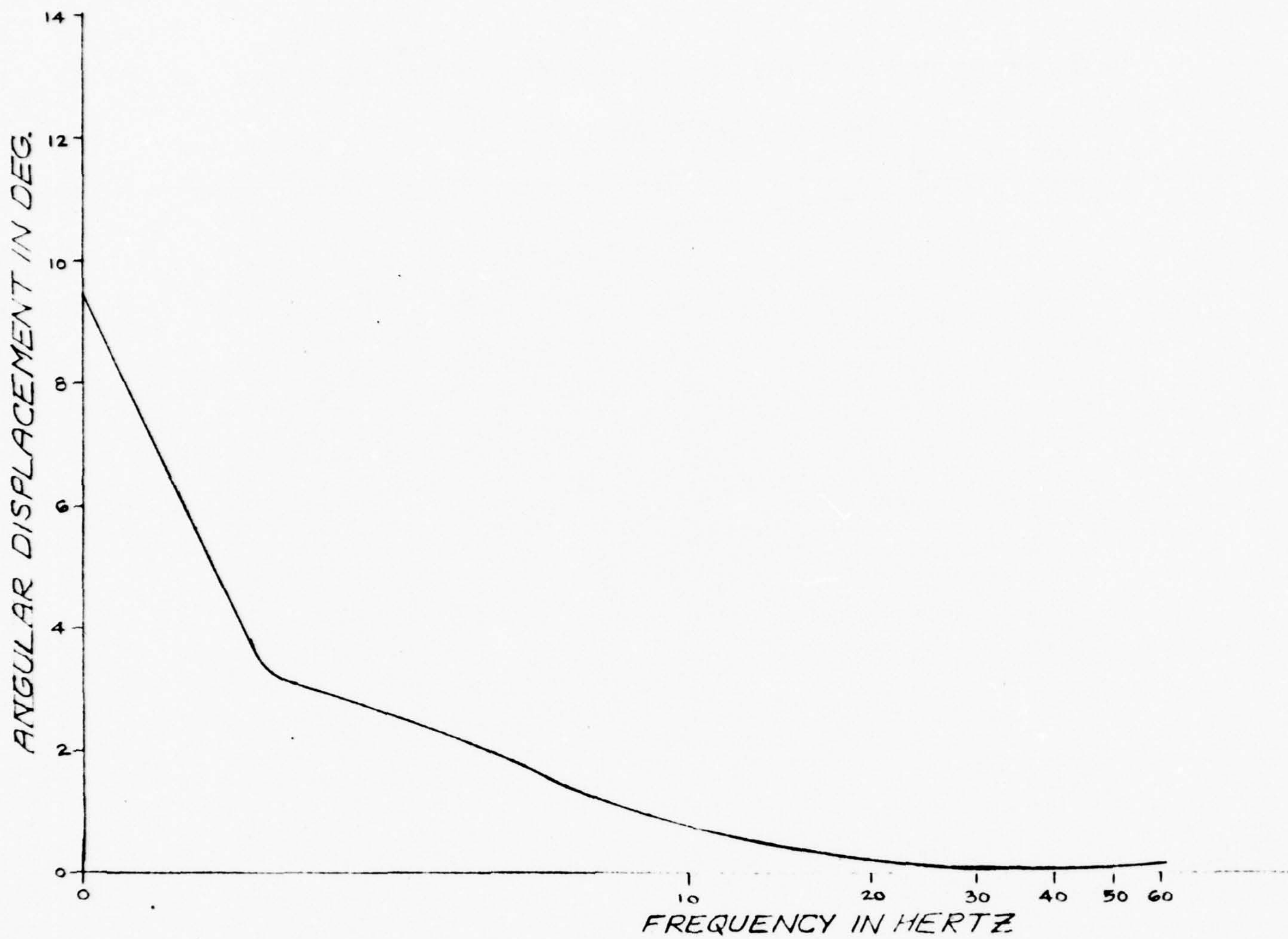


Figure 26. Pitch Axis, Angular Displacement, Tape Input, No Load on the Table, Input .707 VRMS

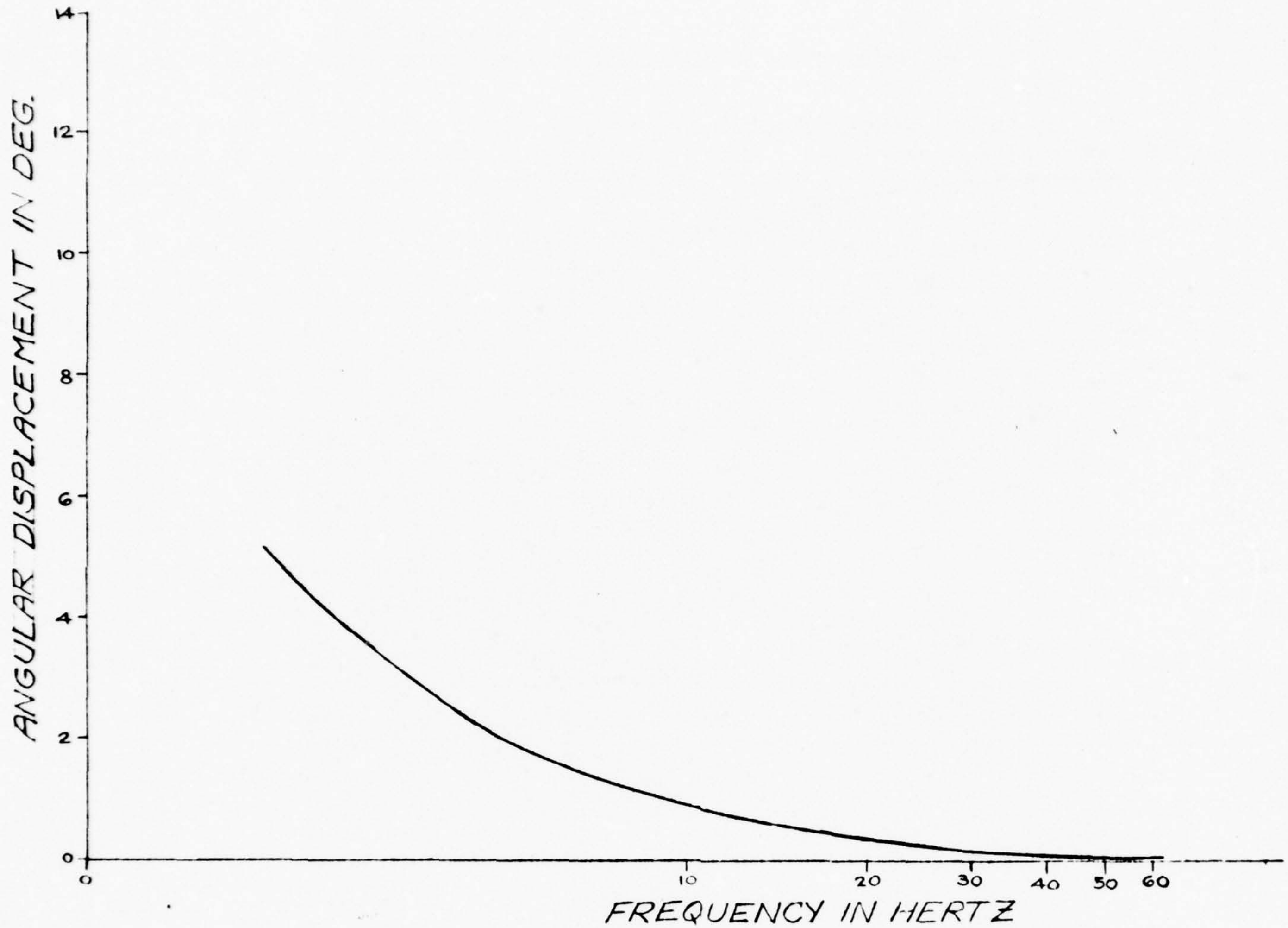


Figure 27. Roll Axis, Angular Displacement, Tape Input, No Load on the Table, Input .707 VRMS

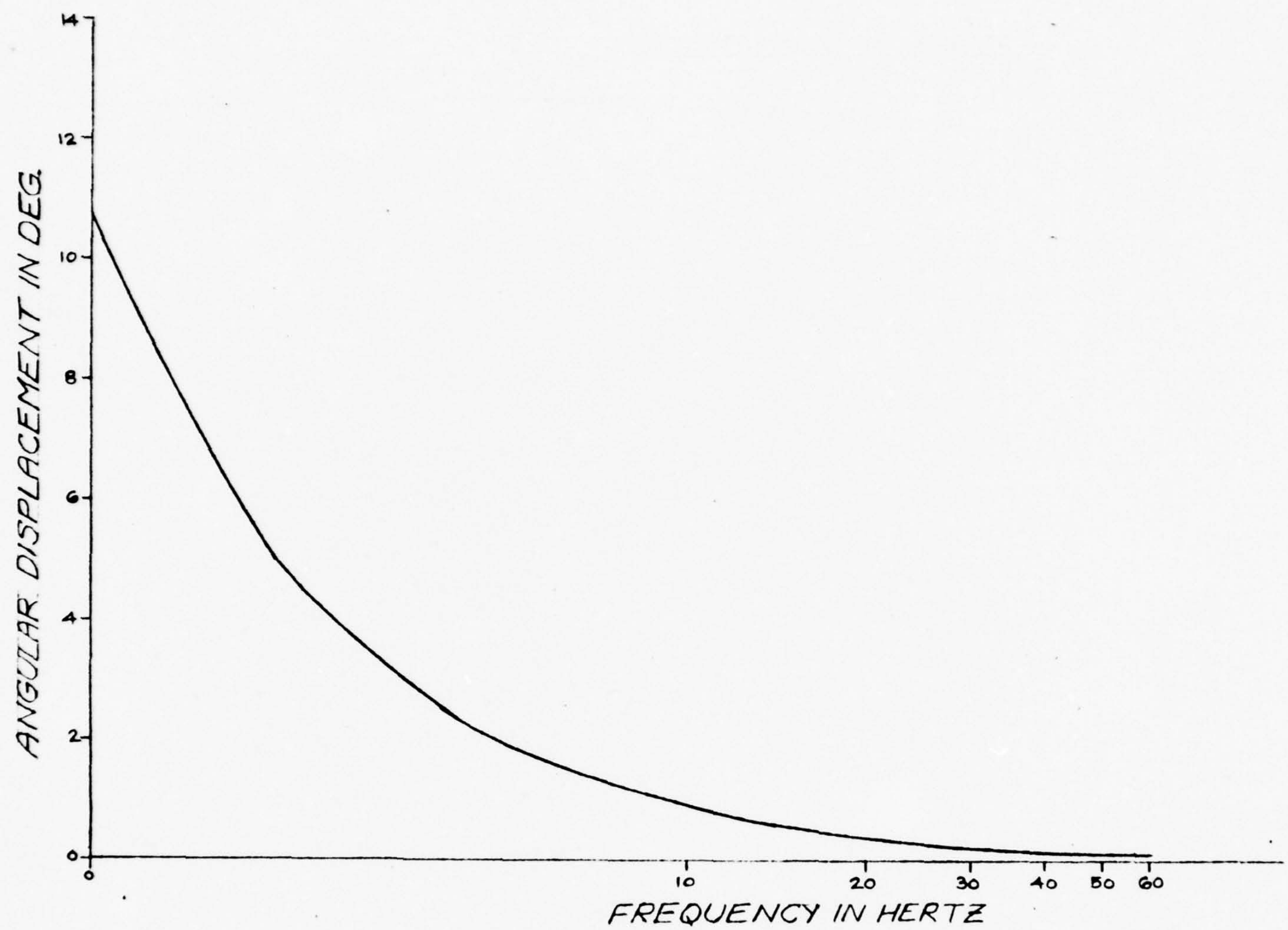


Figure 28. Yaw Axis, Angular Displacement, Tape Input, No Load on the Table, Input .707 VRMS

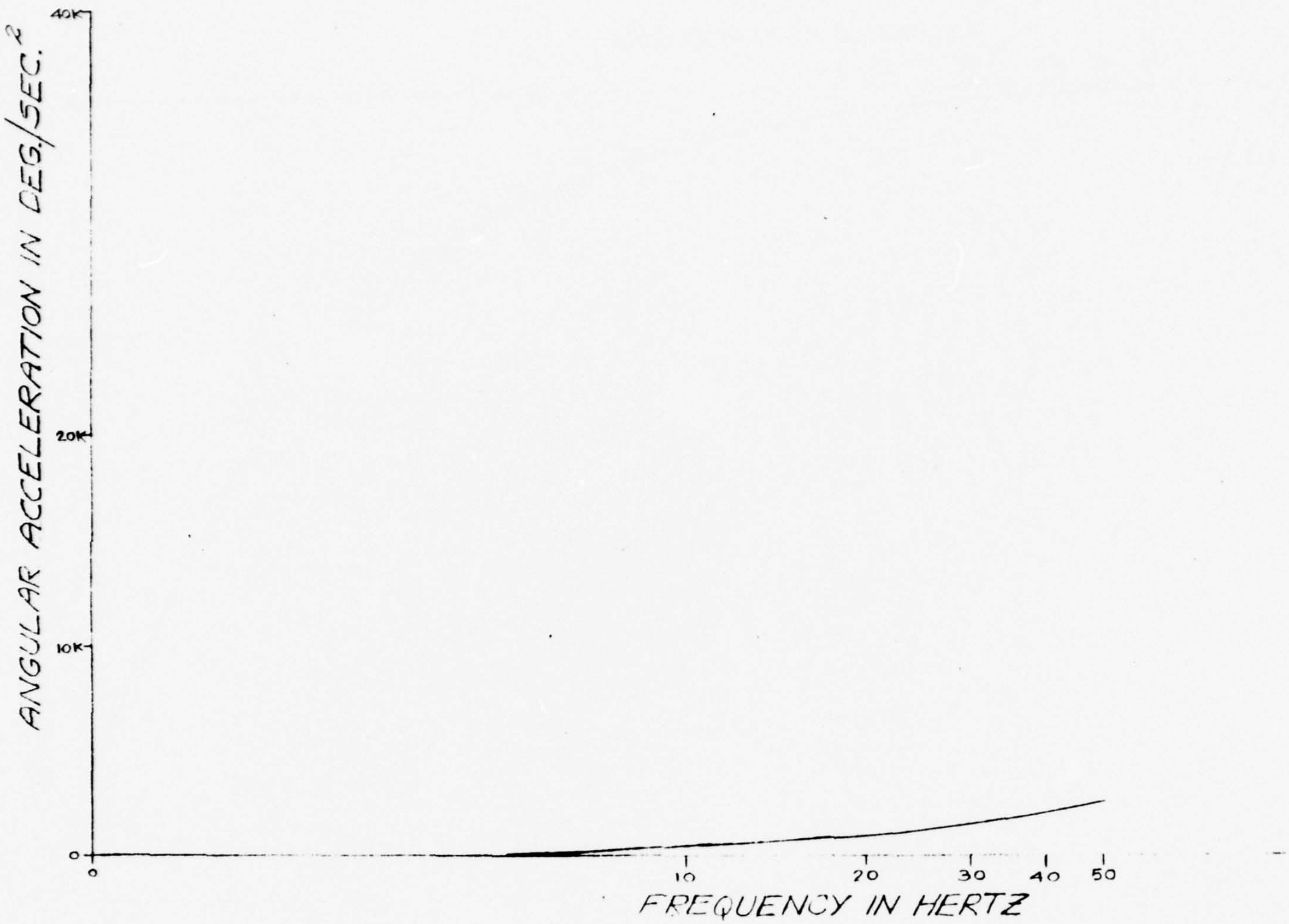


Figure 29. Pitch Axis, Angular Acceleration, Tape Input With Shaping Network, Input .707 to 2.75 VRMS

Figure 30. Roll Axis, Angular Acceleration, Tape Input Using Shaping Network, Input .707 to 1.40 VRMS

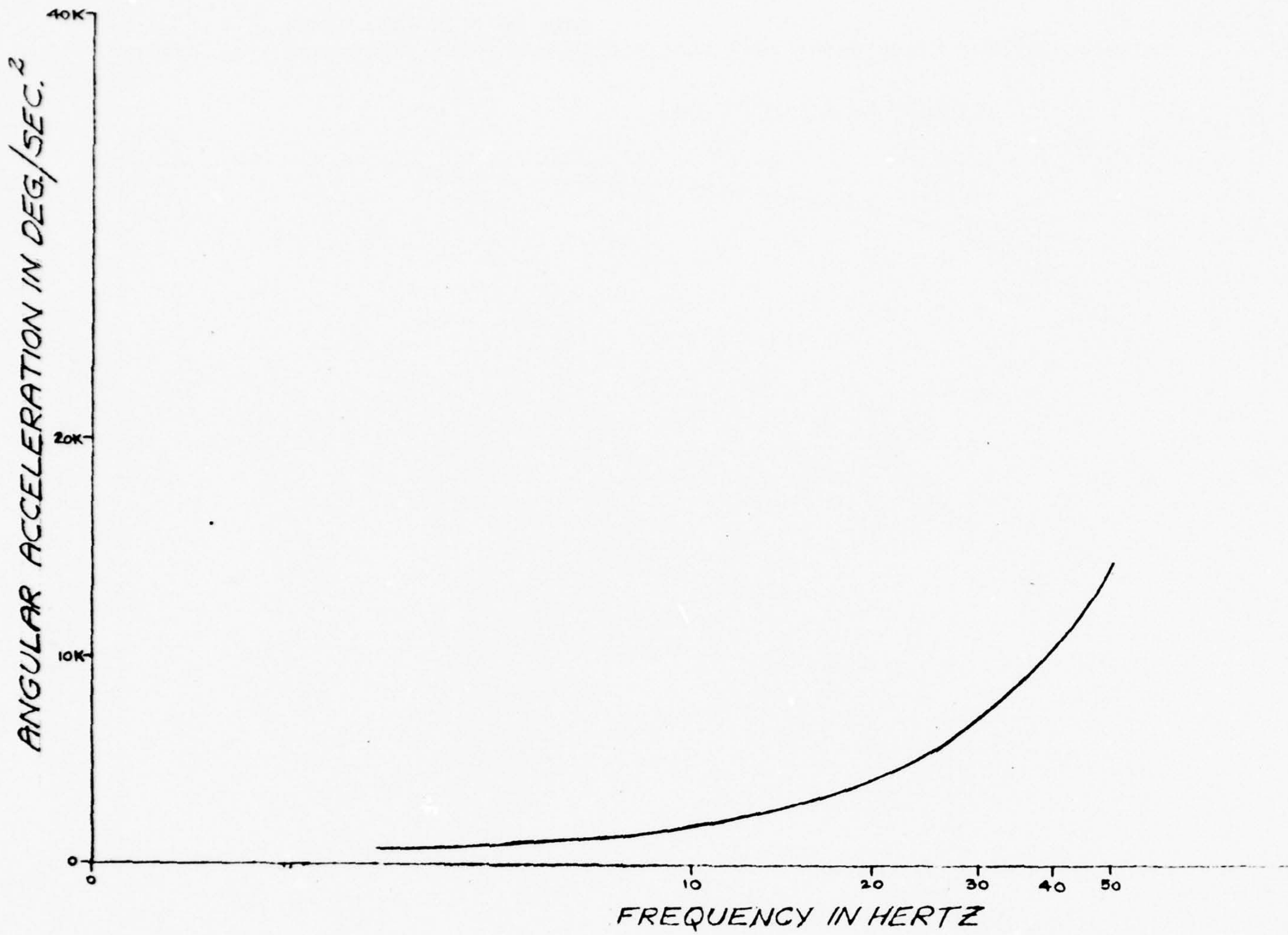


Figure 31. Yaw Axis, Angular Acceleration, Tape Input Using Shaping Network, Input .707 to 2.15 VRMS

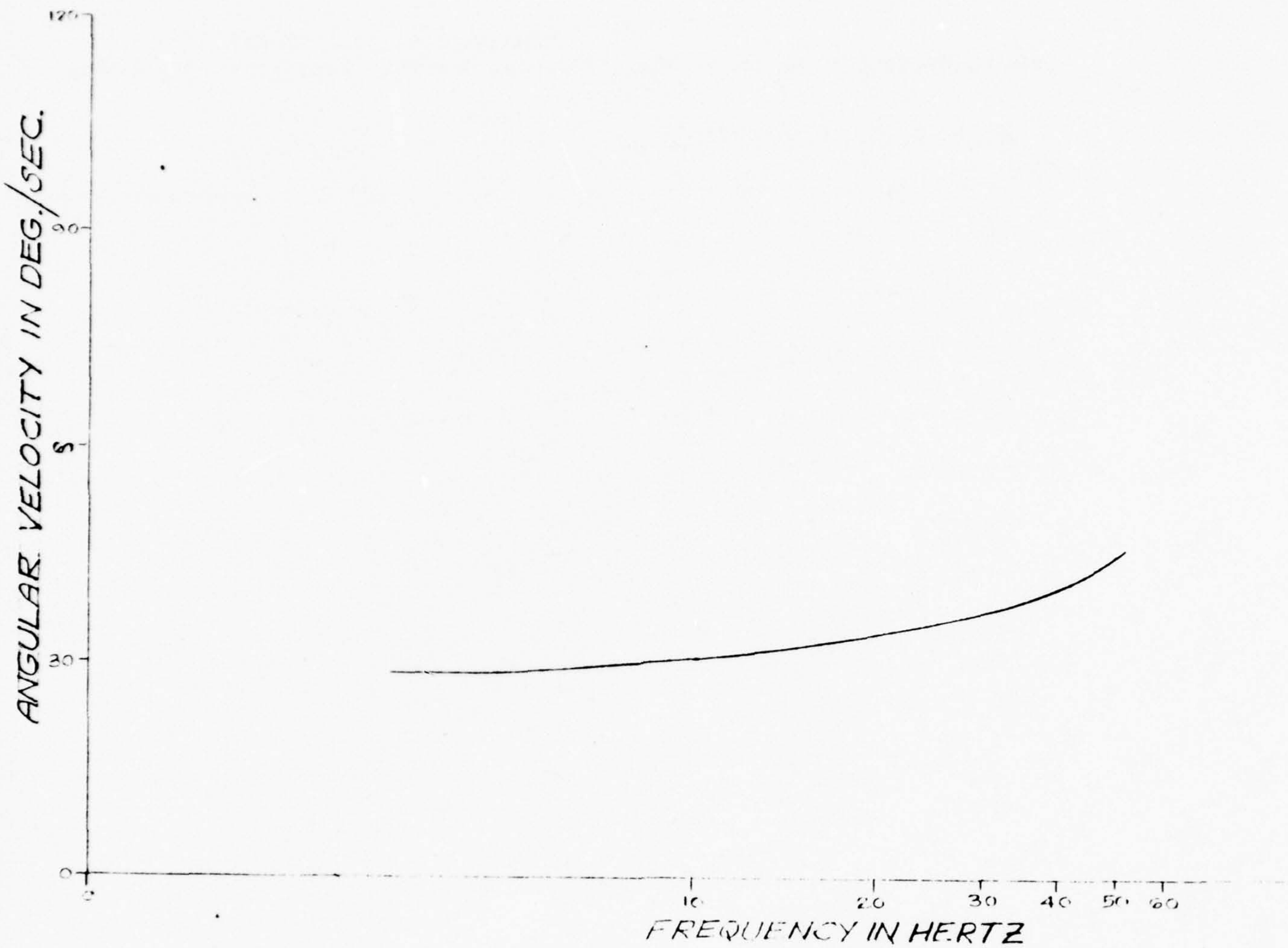


Figure 32. Pitch Axis, Angular Velicity, Tape Input Using Shaping Network, Input .707 to 1.40 VRMS

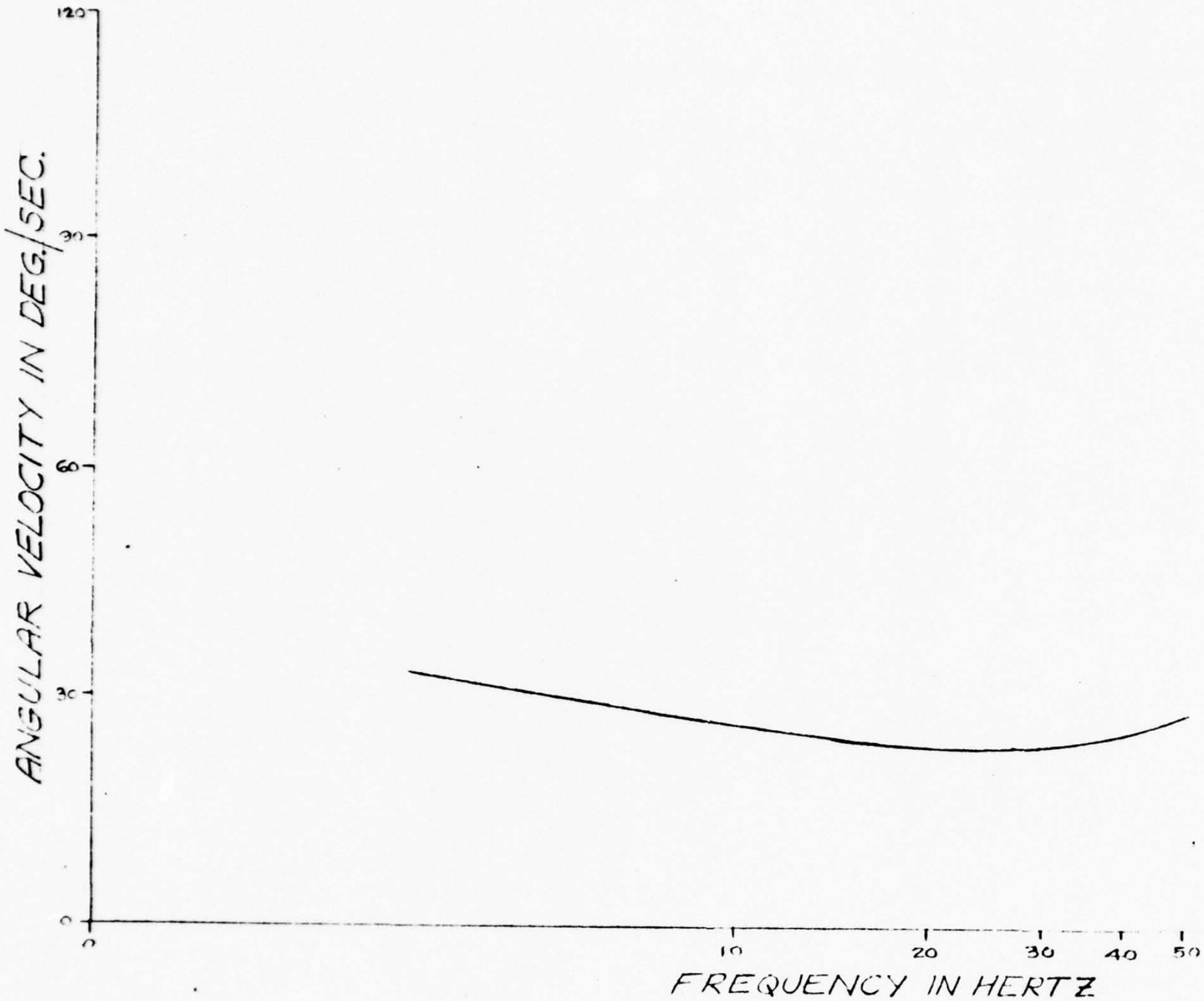


Figure 33. Roll Axis, Angular Velocity, Tape Input Using Shaping Network, Input, .707 to 1.40 VRMS

Figure 34. Yaw Axis, Angular Velocity, Tape Input Using Shaping Network, Input .707 to 2.15 VRMS

Figure 35. Pitch Axis, Angular Displacement, Tape Input Using Shaping Network, Input .707 to 2.75 VRMS

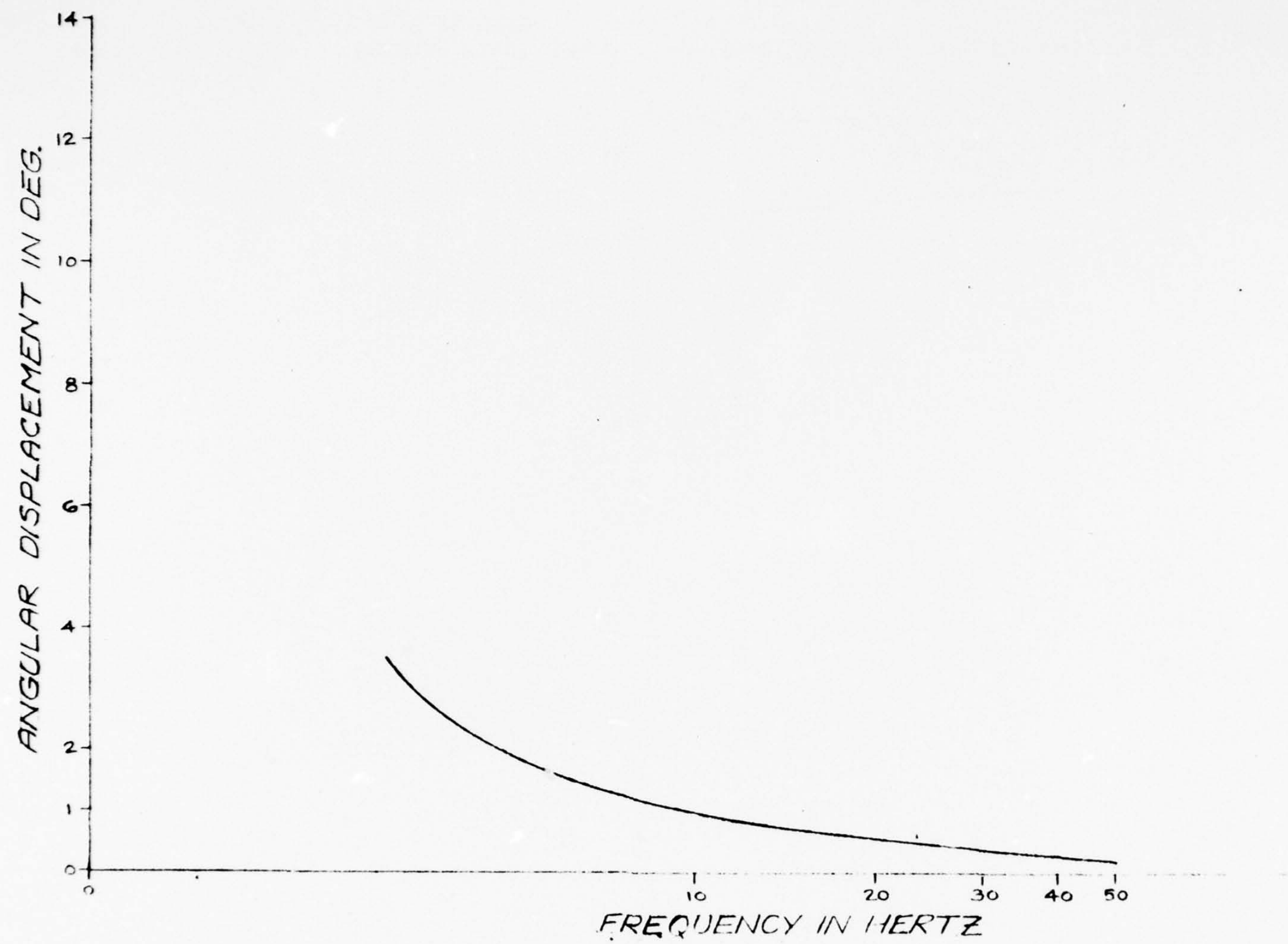


Figure 36. Roll Axis, Angular Displacement, Tape Input Using Shaping Network, Input .707 to 1.40 VRMS

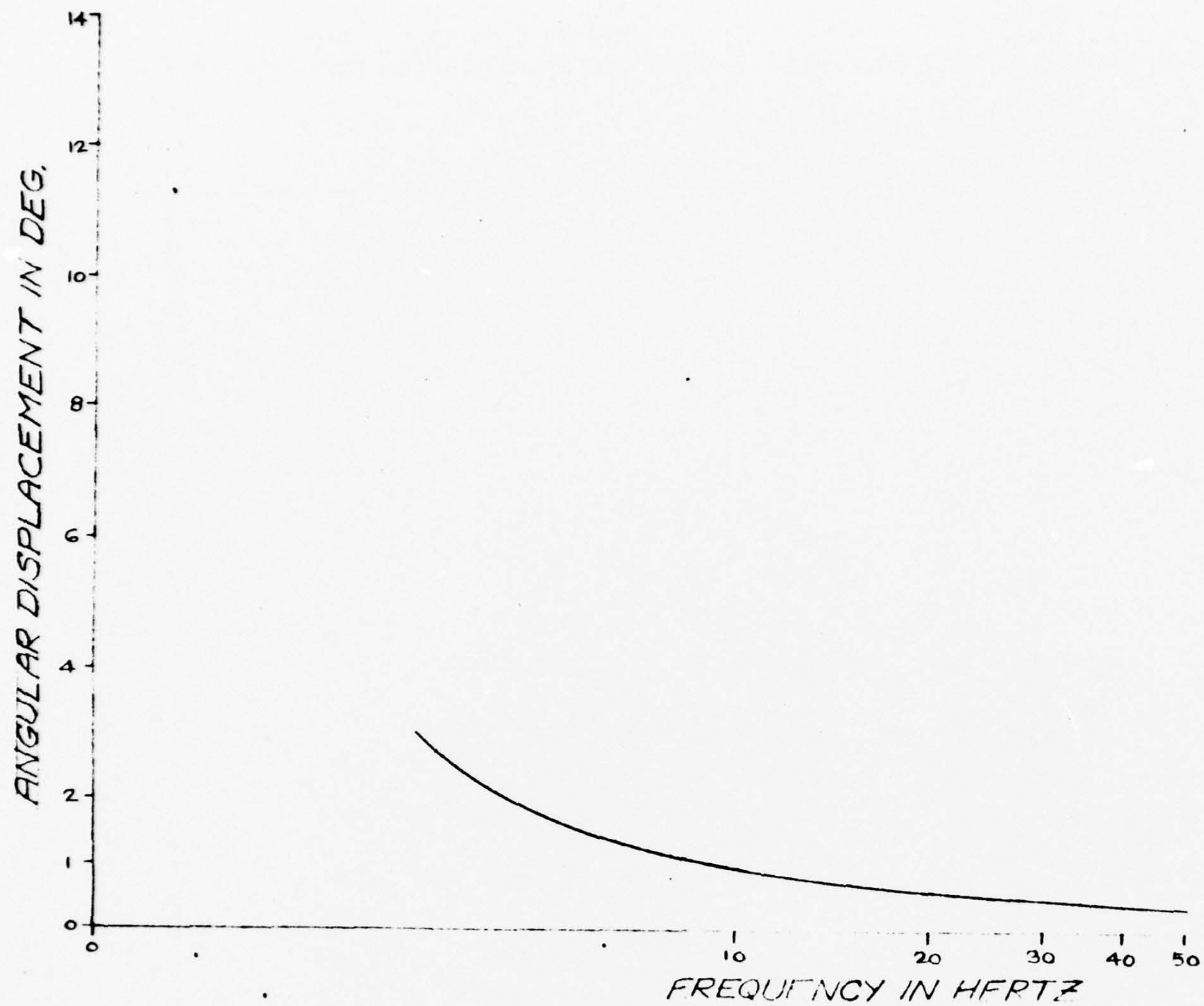


Figure 37. Yaw Axis, Angular Displacement, Tape Input Using Shaping Network, Input .707 to 2.15 VRMS

The characteristic curves shown in Figures 11-19 of the manual mode of operation and Figures 20-28 of the tape mode of operation show that the FMS is not linear up to 50 Hertz, however, Figures 29-33 show that by use of the shaping networks shown in Figures 8 and 9 the output of the FMS can be made practically linear.

EVALUATION PROCEDURE - Phase 2

The second phase of the test program was designed to determine the ability of the FMS to simulate the angular rates of motion of a helicopter. It was first necessary to determine the nature of representative inputs. The most realistic method of determining helicopter inputs is to place a fire control instrument in a helicopter in its normal operating position, instrument it with vibration transducers and record the motions being transmitted to it by the helicopter onto tape. The tape would then be used to operate the FMS in the tape mode and an analysis of the tape together with existing helicopter specifications would provide data sufficient to operate in the manual mode.

For this investigation, a tape of a flight test which had been performed on an AM76 Fire Control Sight mounted in a "Bell" AH-1 helicopter was used as representative of angular motions experienced in helicopters. The sensor package used to record this tape of helicopter motions consisted of three Humphrey Model RG51-0801-1 Rate Gyros mounted on the gunners seat in positions to sense vibrations in the pitch, roll and yaw axes. The Rate Gyro output signals were recorded on 1-inch magnetic tape using a Sangamo Model 3500 FM tape recorder operated at 7½ inches/sec.

The three channels of information recorded on the tape were played simultaneously through the tape input of the Simulator, one channel each into the pitch, roll and yaw axis. Since the information recorded on the tape used for this test is velocity, or rate, it was possible to measure Simulator output directly from an output jack mounted on the control console for the purpose of monitoring rate. To simplify the task of comparing the input to the table command and the Simulator table output, the input and output were recorded on adjacent channels of a Bell and Howell Datagraph Model 5-134 recorder. The recorder print outs of these comparisons are shown in Figures 38 through 42, and in Vibration Spectra, Figures 44 through 47.

EVALUATION PROCEDURE - Phase 3

The third phase of the program was to determine if the FMS could be used to perform, adequately, vibration tests on helicopter fire control instrumentation as is called out in existing specifications. During this portion of the program, test criteria was established by using Military Standards used in testing helicopter fire control instrumentation by converting linear requirements into angular data and from an analysis of the pre-recorded tape of helicopter motion. The analysis of the tape revealed predominant frequencies of 11, 12 and 33 Hertz.

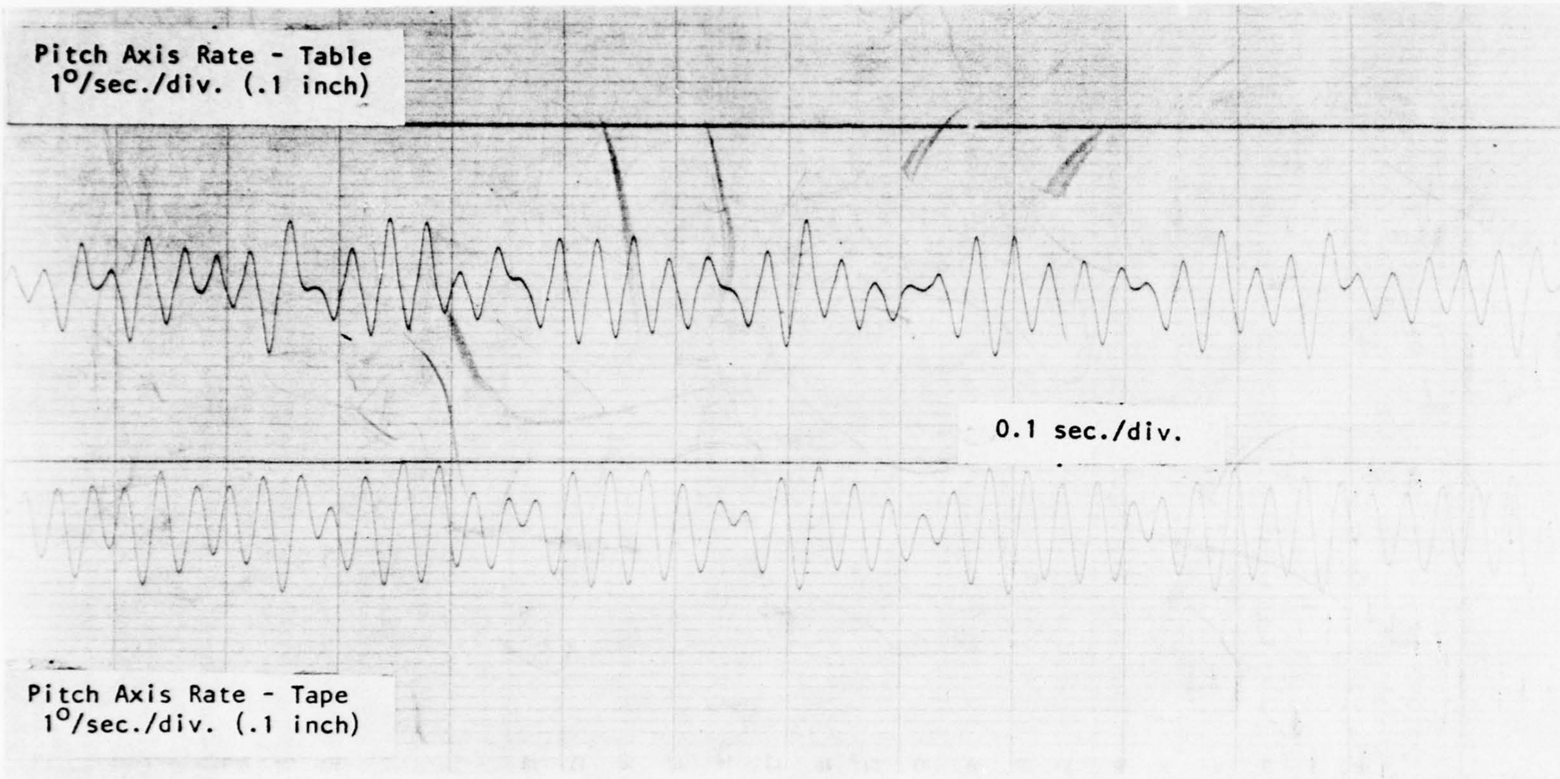


Figure 38. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Pitch Axis

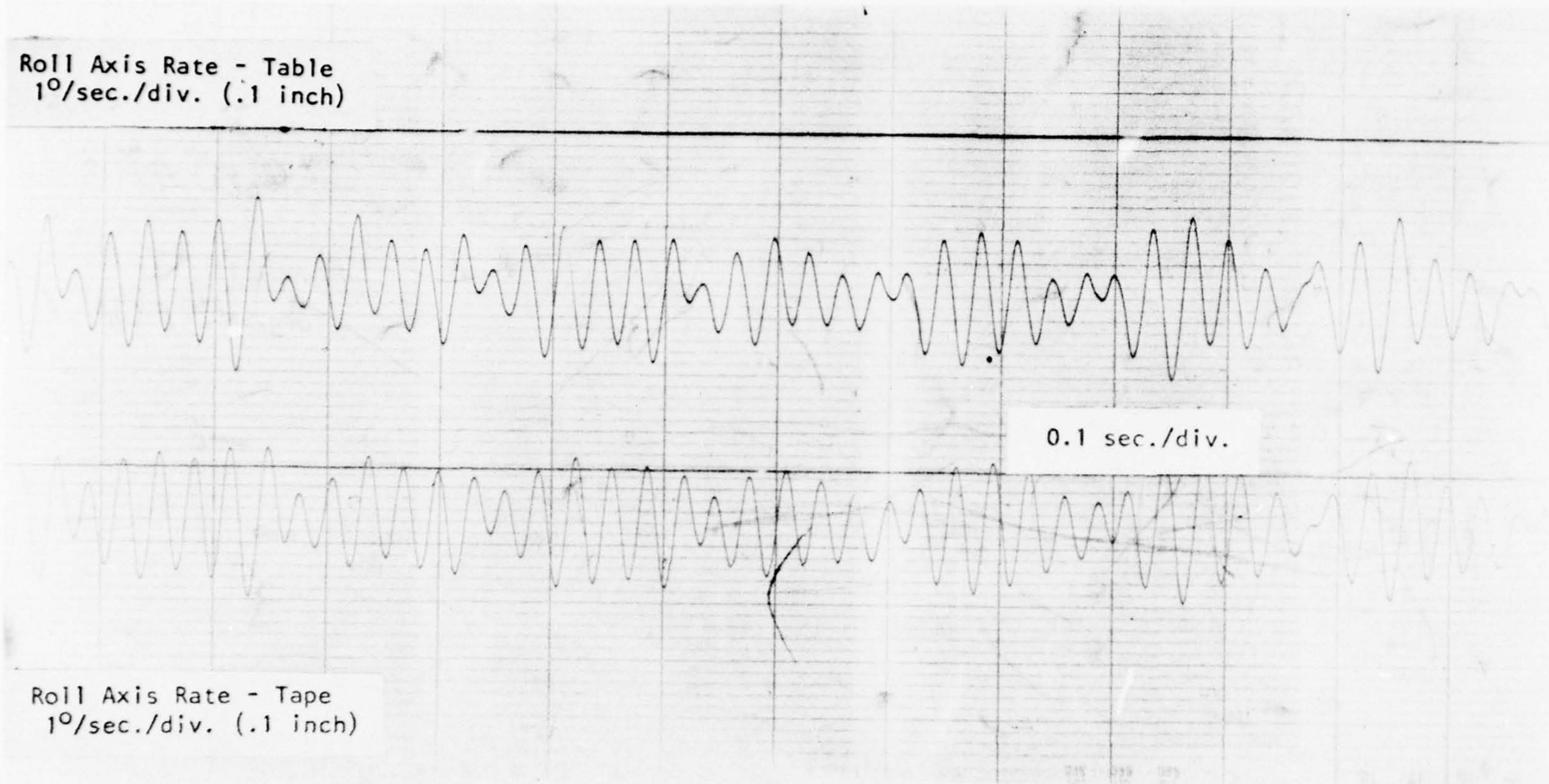


Figure 39. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Roll Axis

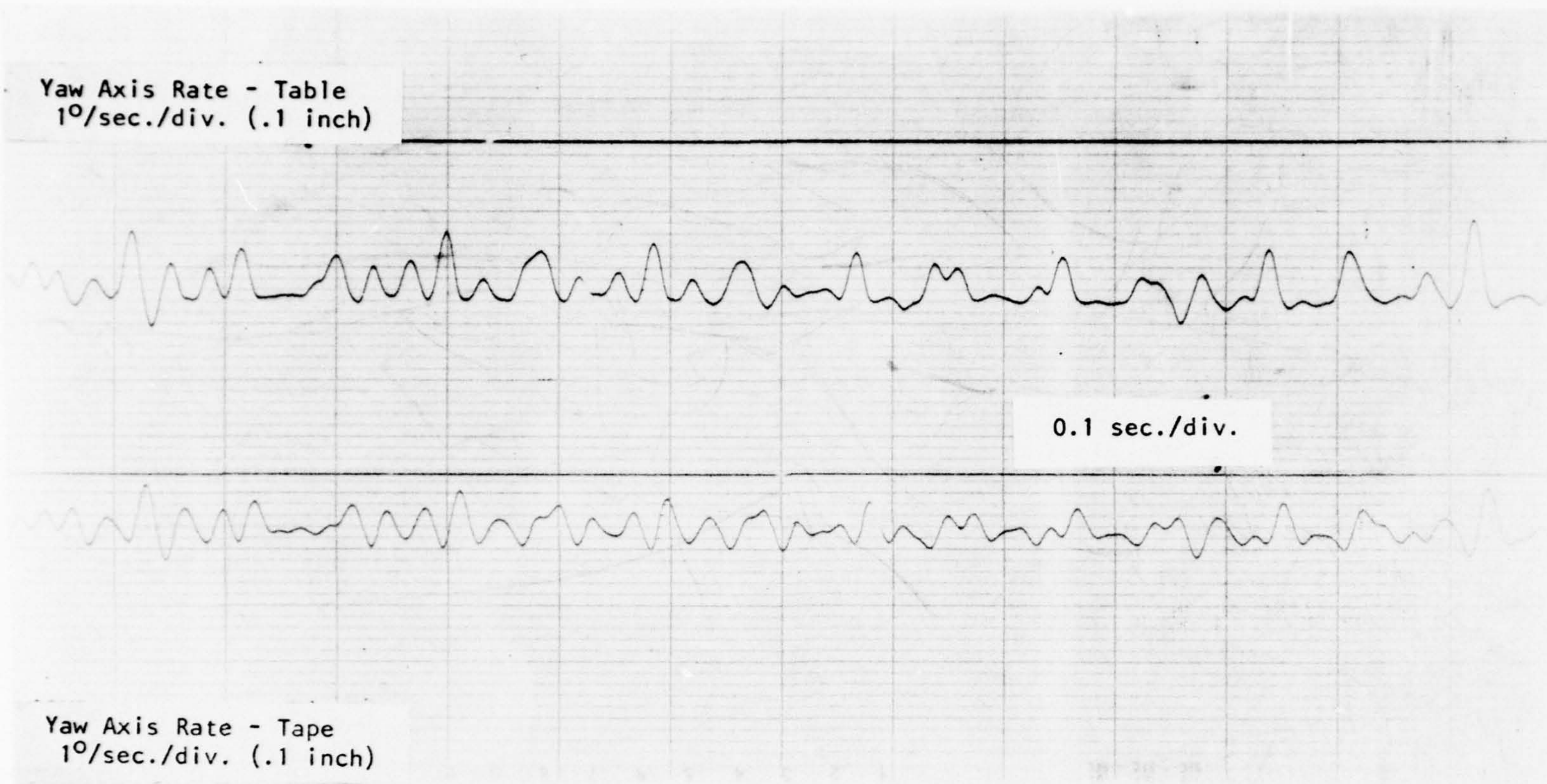
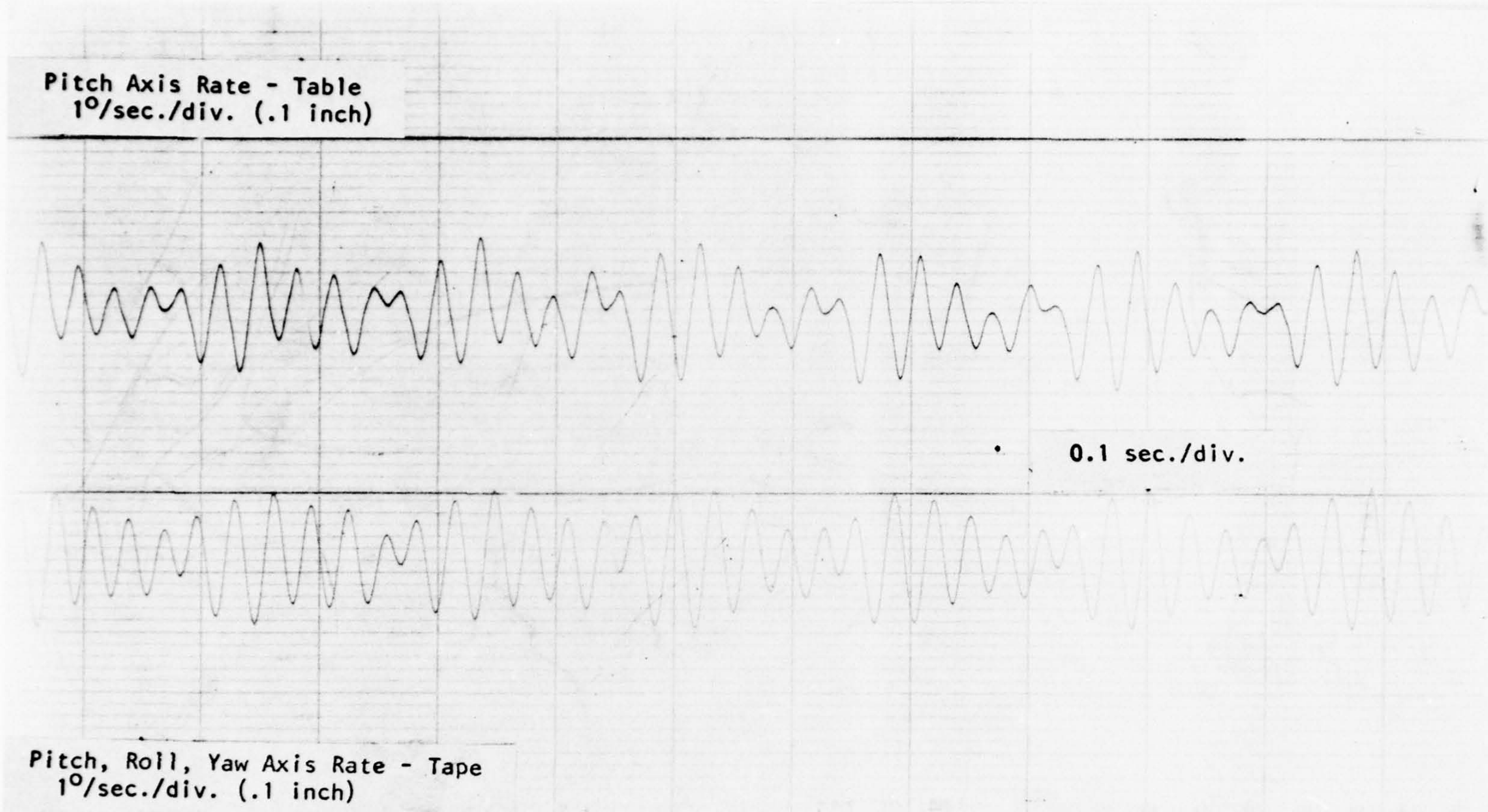
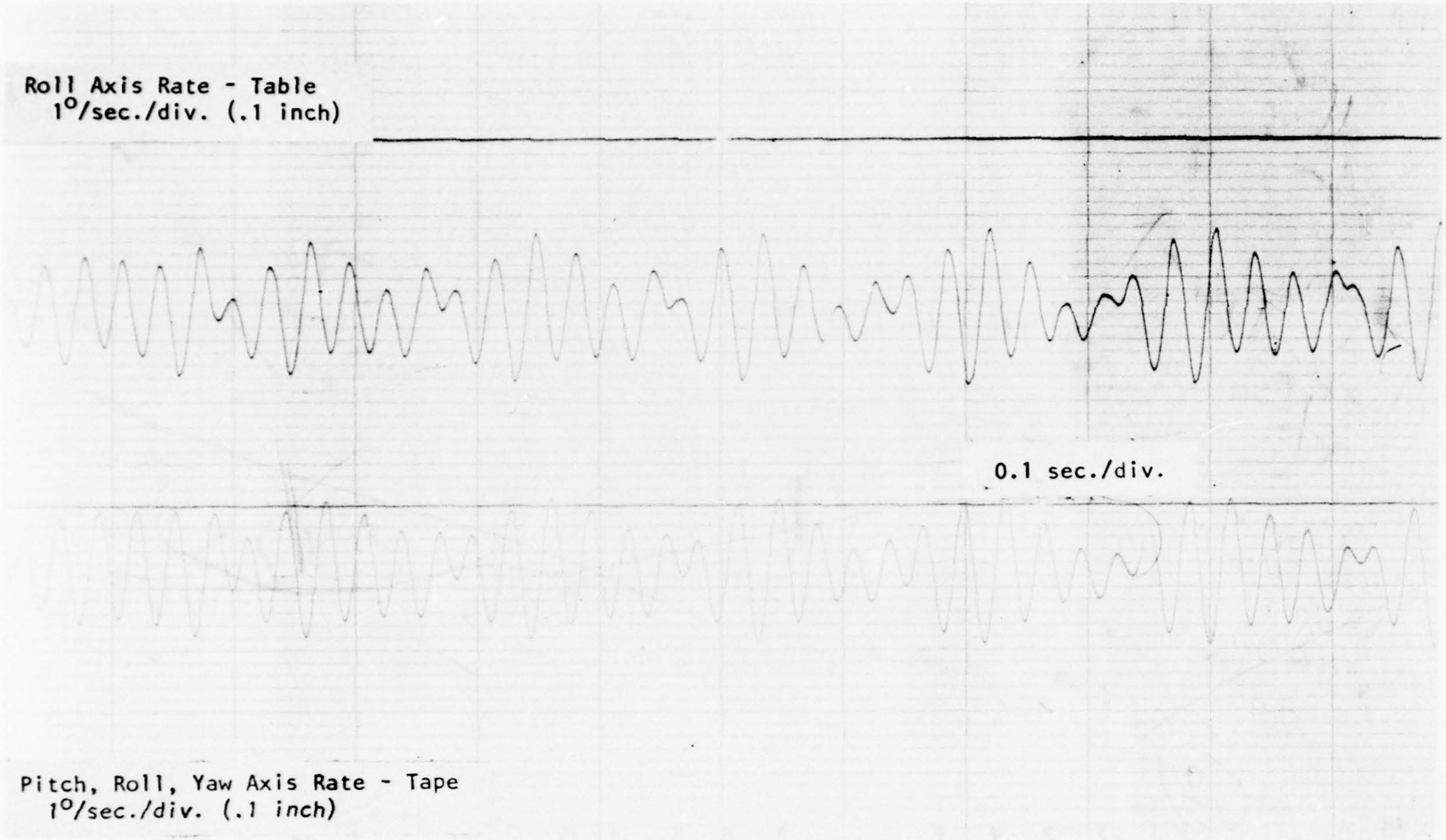


Figure 40. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Yaw Axis



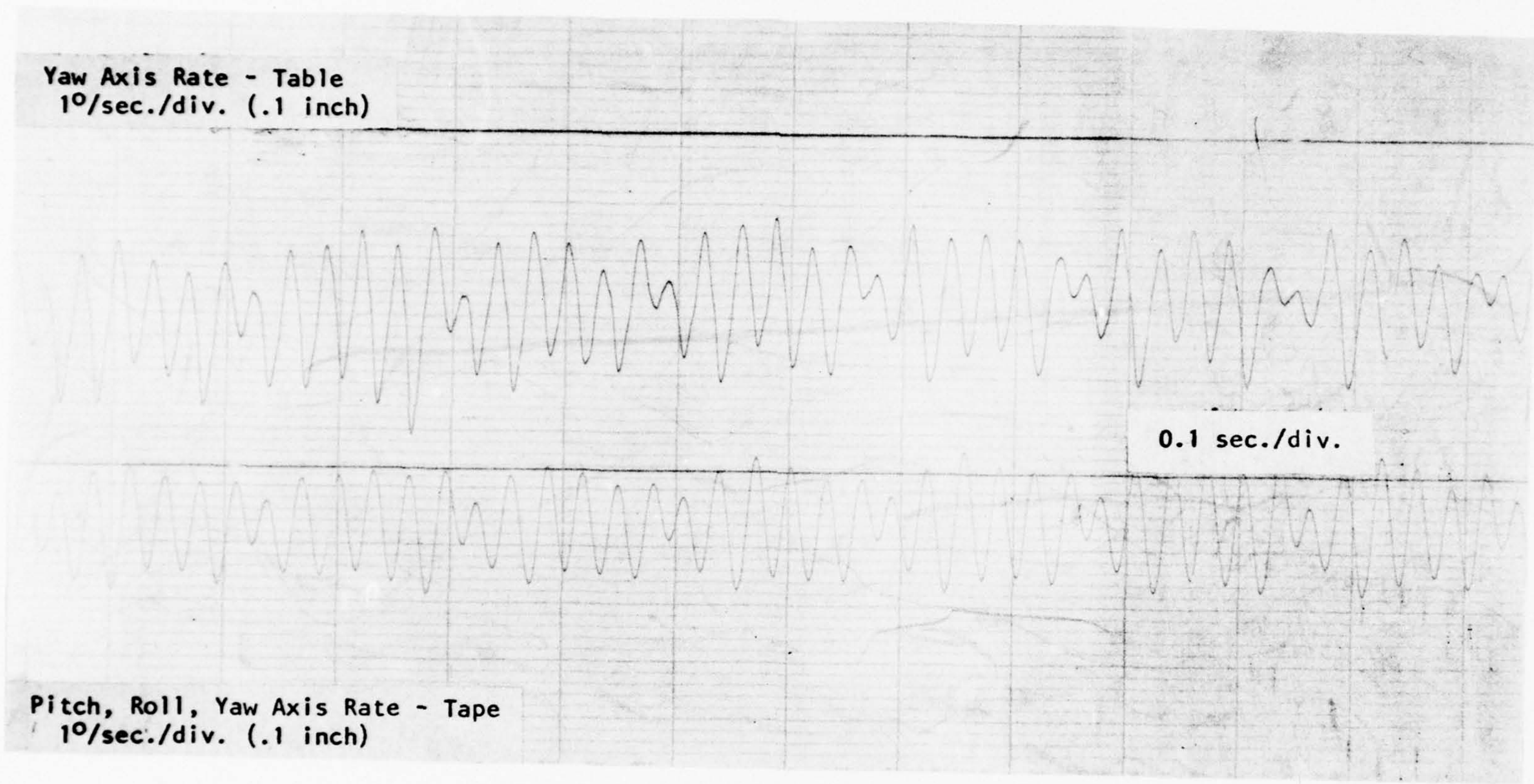
Same input to Pitch, Roll & Yaw axes - - Pitch axis output recorded.

Figure 41. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Pitch Axis



Same input to Pitch, Roll & Yaw axes - - Roll axis output recorded.

Figure 42. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Roll Axis



Same input to Pitch, Roll & Yaw axes - - Yaw axis output recorded.

Figure 43. Comparison of FMS Table Output Vs AH-1G Helicopter Tape Input: Yaw Axis

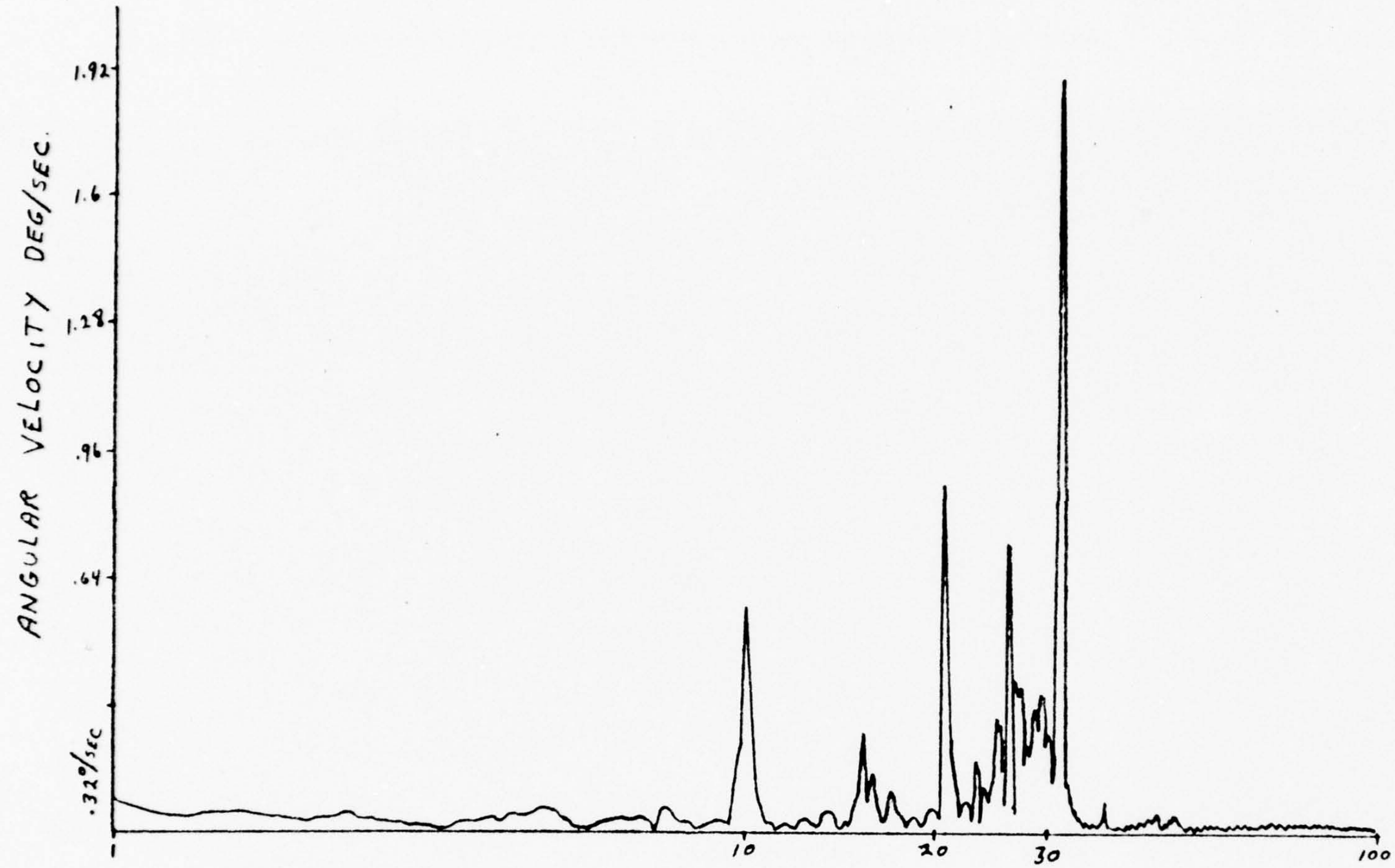


Figure 44. Vibration Spectrum recorded in the Pitch Axis of the AH-1G Helicopter

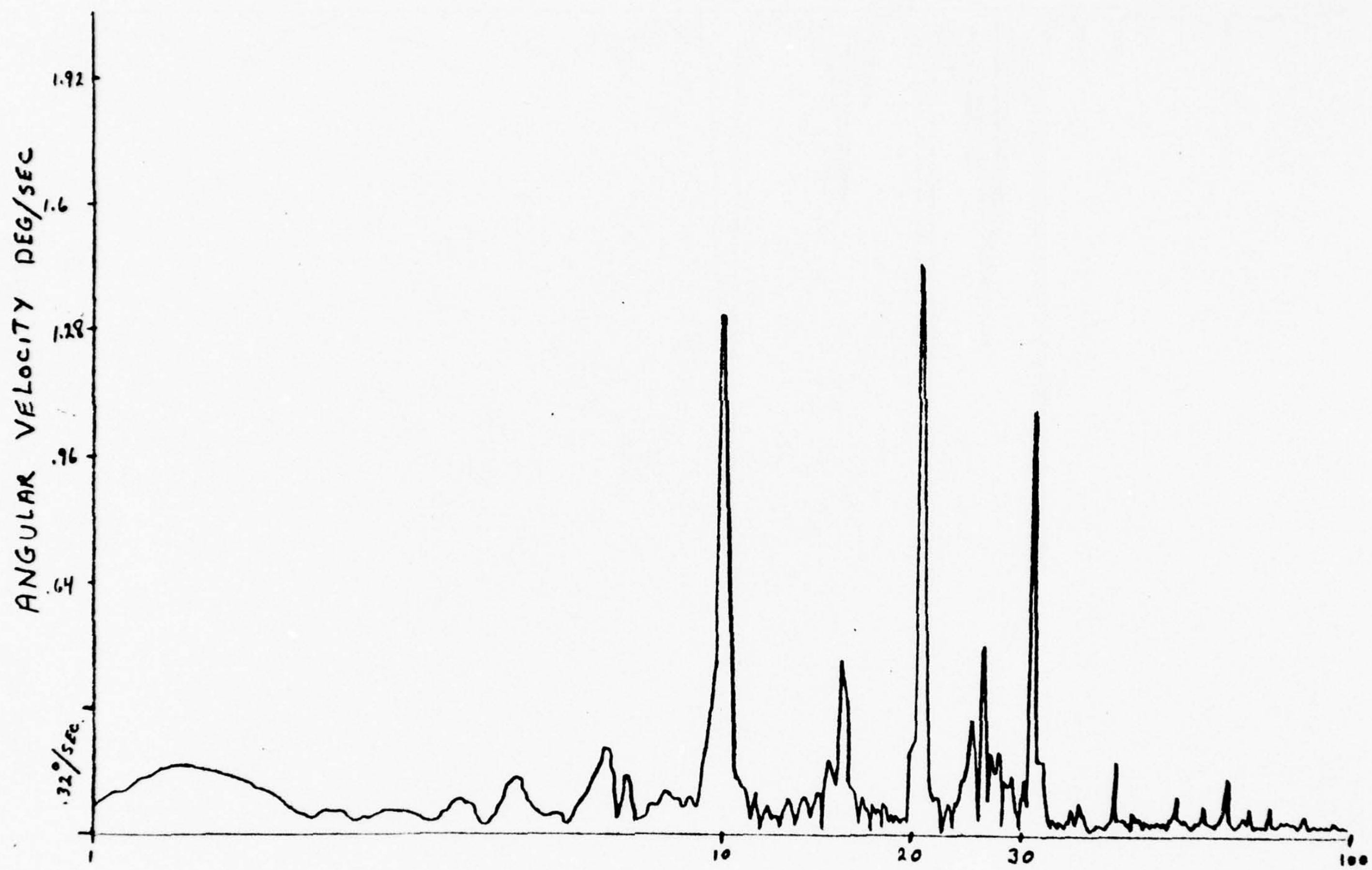


Figure 45. Vibration Spectrum - Recording of FMS Pitch Axis Output

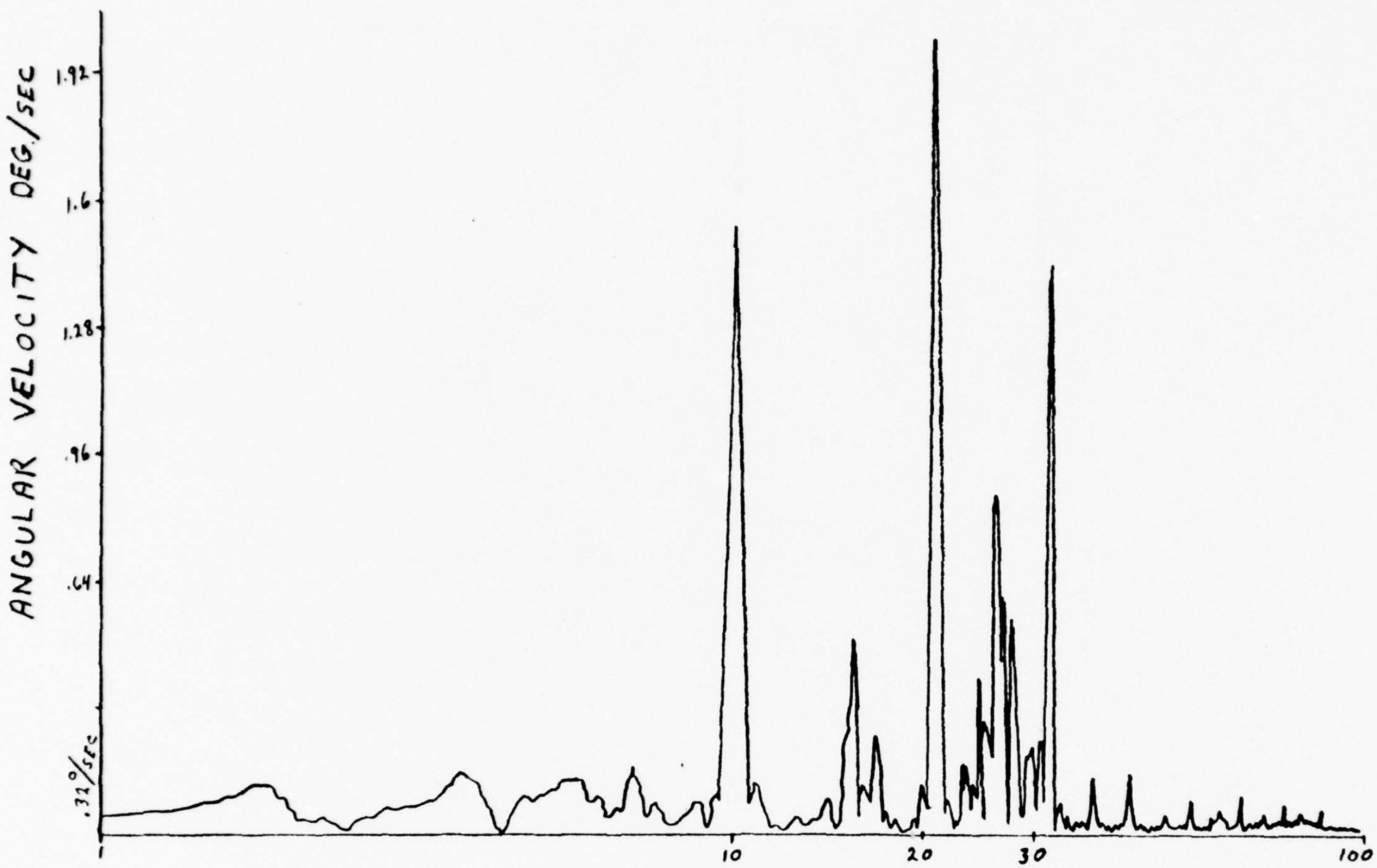


Figure 46. Vibration Spectrum - Recording of FMS Roll Axis Output

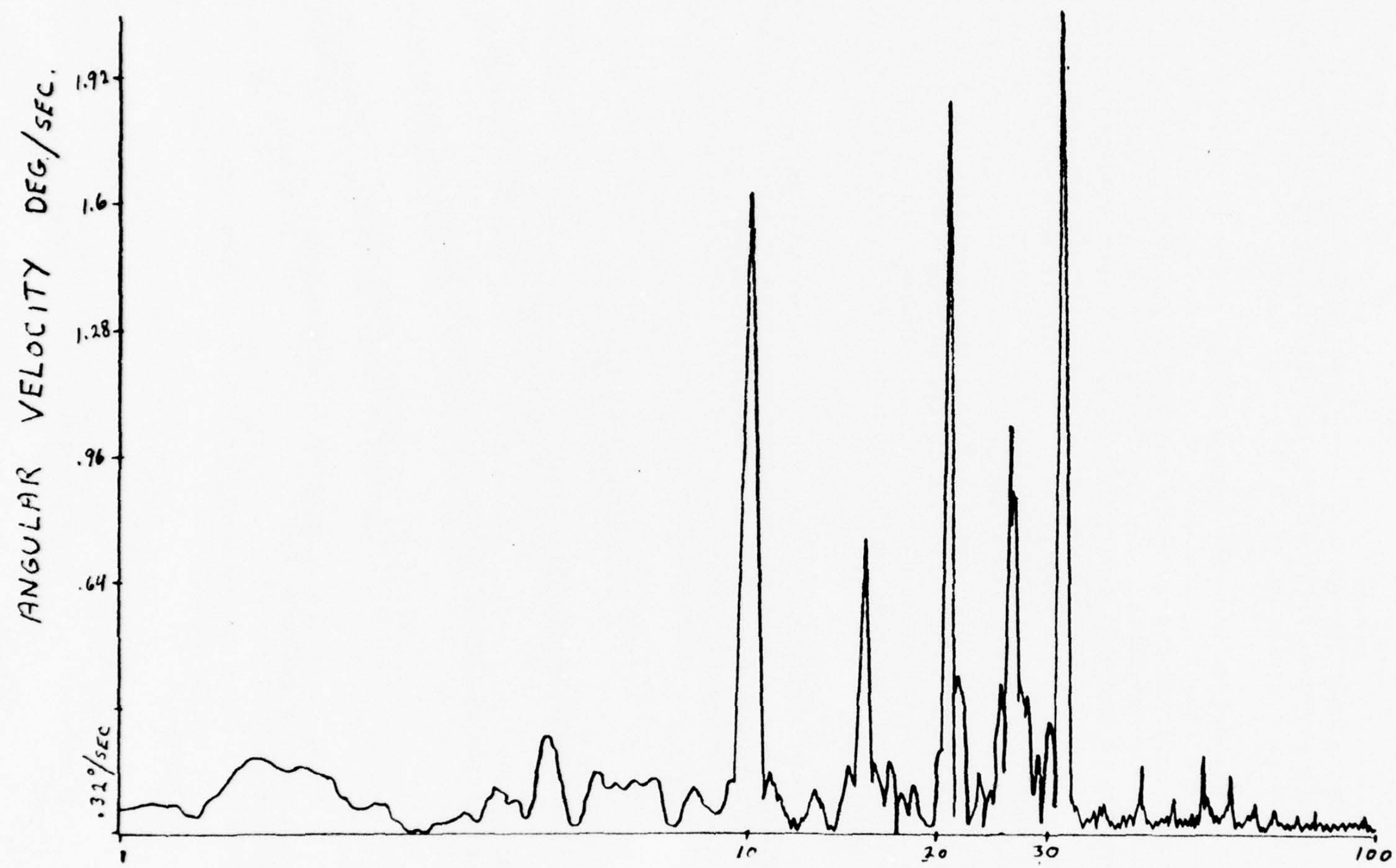


Figure 47. Vibration Spectrum - Recording of FMS Yaw Axis Output

Knowing that the FMS has frequency limitations, that is, the frequency response falls off sharply beyond 40 Hertz, this testing was confined to frequencies of 50 Hertz and below.

It was determined that with a voltage input of 0.522 volts we could maintain a linear displacement of 0.2 inches double amplitude and with a voltage input of 0.4 we could maintain a g output of 2 g's on the Roll axis of the FMS Table. For the Pitch axis an input voltage of 0.516 was required to maintain a displacement of 0.2 inches double amplitude and an input voltage of 0.5 was required to maintain a g level of 2 g's. The Yaw axis required a voltage of 0.557 volts to maintain a displacement of 0.2 inches double amplitude and an input voltage of 0.5 was necessary to sustain 2 g's at the table output. These voltages were applied to the FMS's electronic input and the output was measured. Using the conversion formulas given previously in this report, the output readings were converted to angular values and plotted. The results of this plotted data is shown in Figures 48 through 56 and is explained in the results section of this report.

In this particular application, this was done in order to give the Engineering some insight as to the magnitude of angular motions and should not be mistaken for a method of direct conversion from linear test criteria to angular parameters since all factors other than length of the radius were not considered.

RESULTS OF PHASE 1

These tests established that the linearity of the static response of the system in terms of Table Position readout and Table Actuator Displacement versus Table Position command is better than $\pm$ 3 percent. This is evident from the plots of the data recorded on Data Sheets 1, 2 and 3 and Figures 5, 6 and 7.

RESULTS OF PHASE 2

In these tests the capability to reproduce with the FMS three axis complex rate signals sensed by an orthogonal set of Rate Gyros carried on a helicopter and recorded on magnetic tape is demonstrated. The recording of helicopter motion used for this experiment was the one taken of the pitch axis of the helicopter since the most severe vibration was experienced in this axis.

The results of the tests presented as side-by-side Datagraph recordings of the Tape Rate and Table Rate R/O signals for the pitch, roll and yaw axis respectively (Figures 38-43), shows a very good match of detail rate motion. This run demonstrates:

a. The Table Rate readout is dynamically equivalent to the Rate Gyro readout.

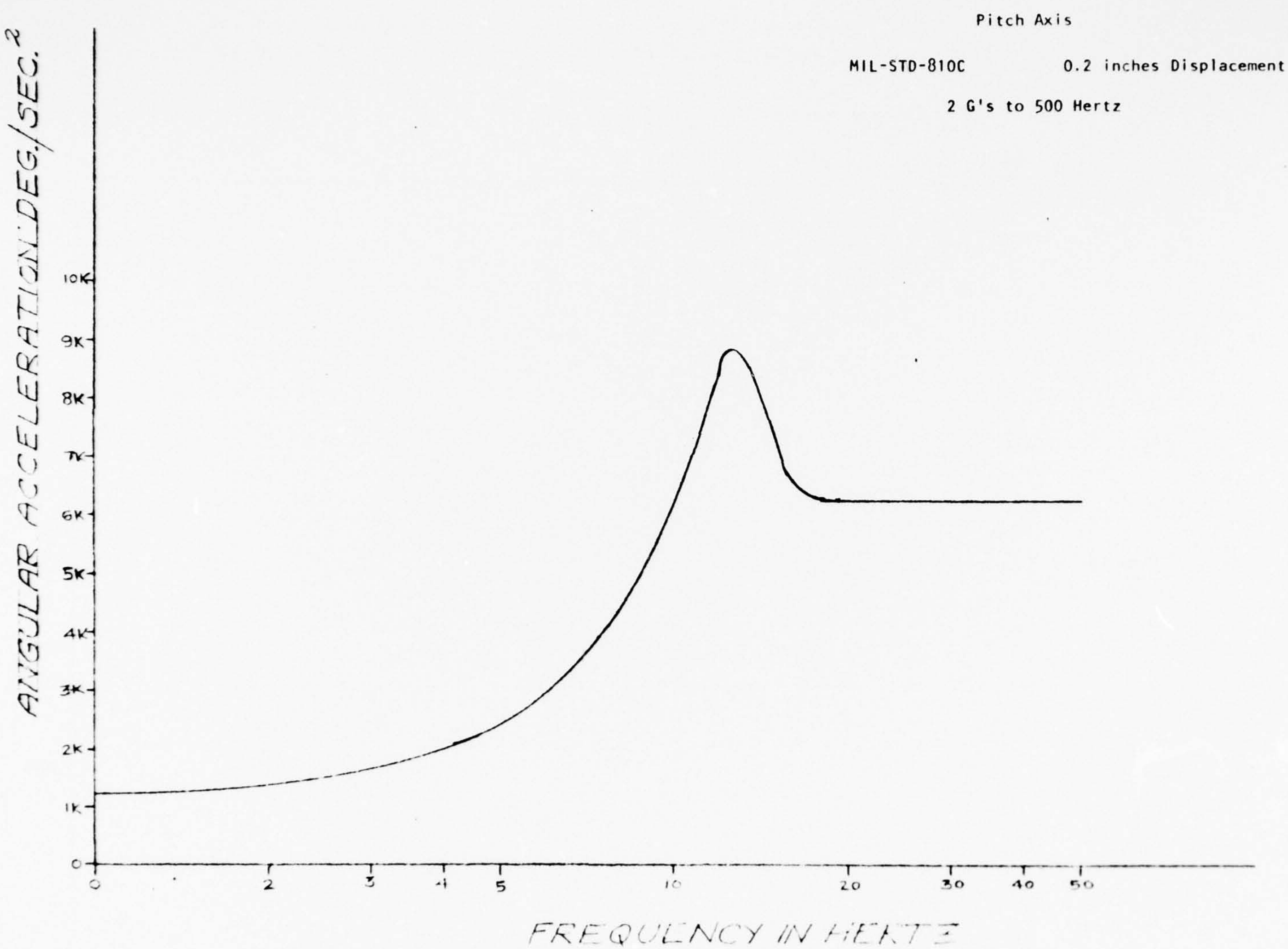


Figure 48. FMS Pitch Axis Angular Acceleration Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

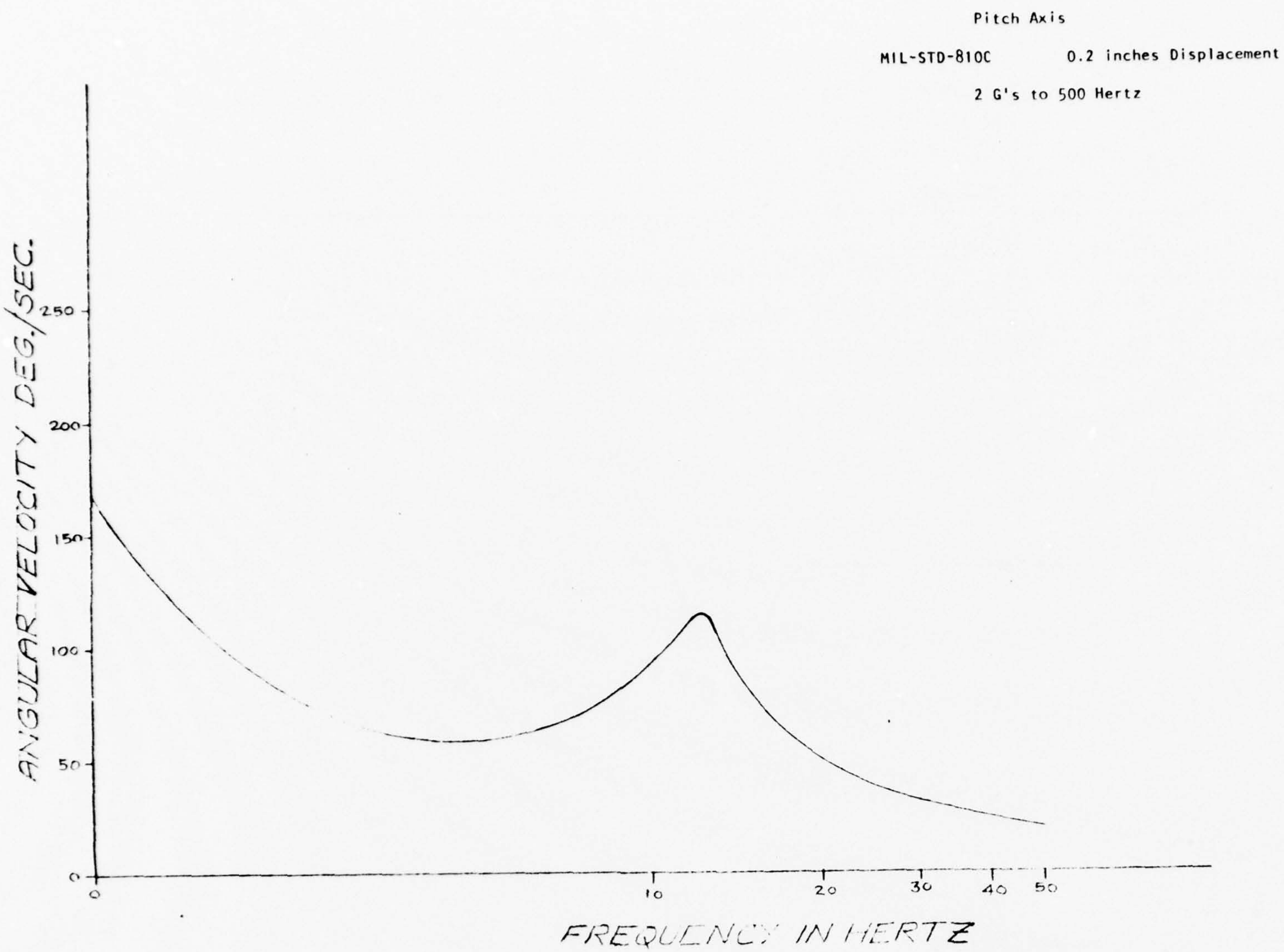


Figure 49. FMS Pitch Axis Angular Velocity Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

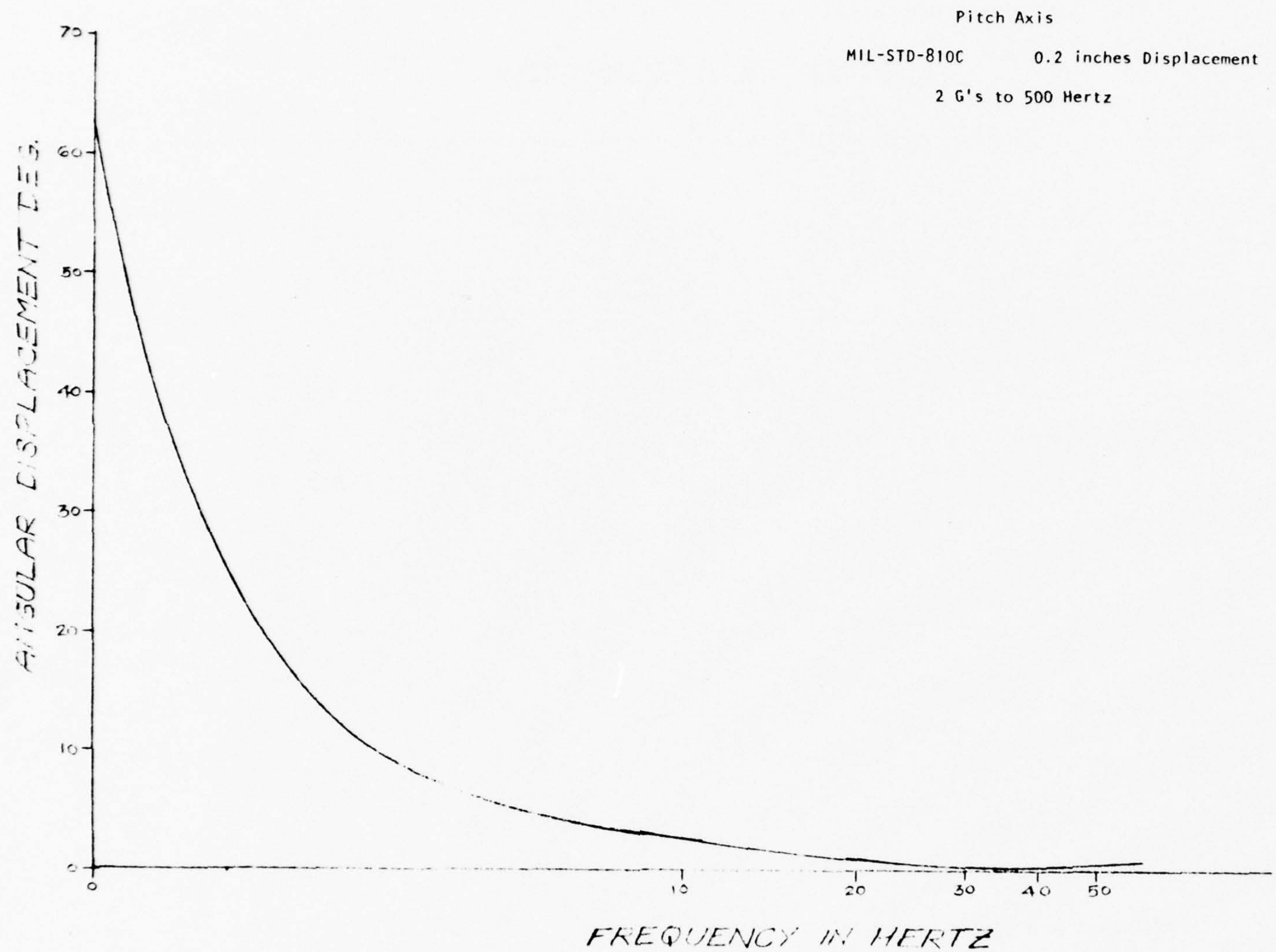


Figure 50. FMS Pitch Axis Angular Dispacement Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

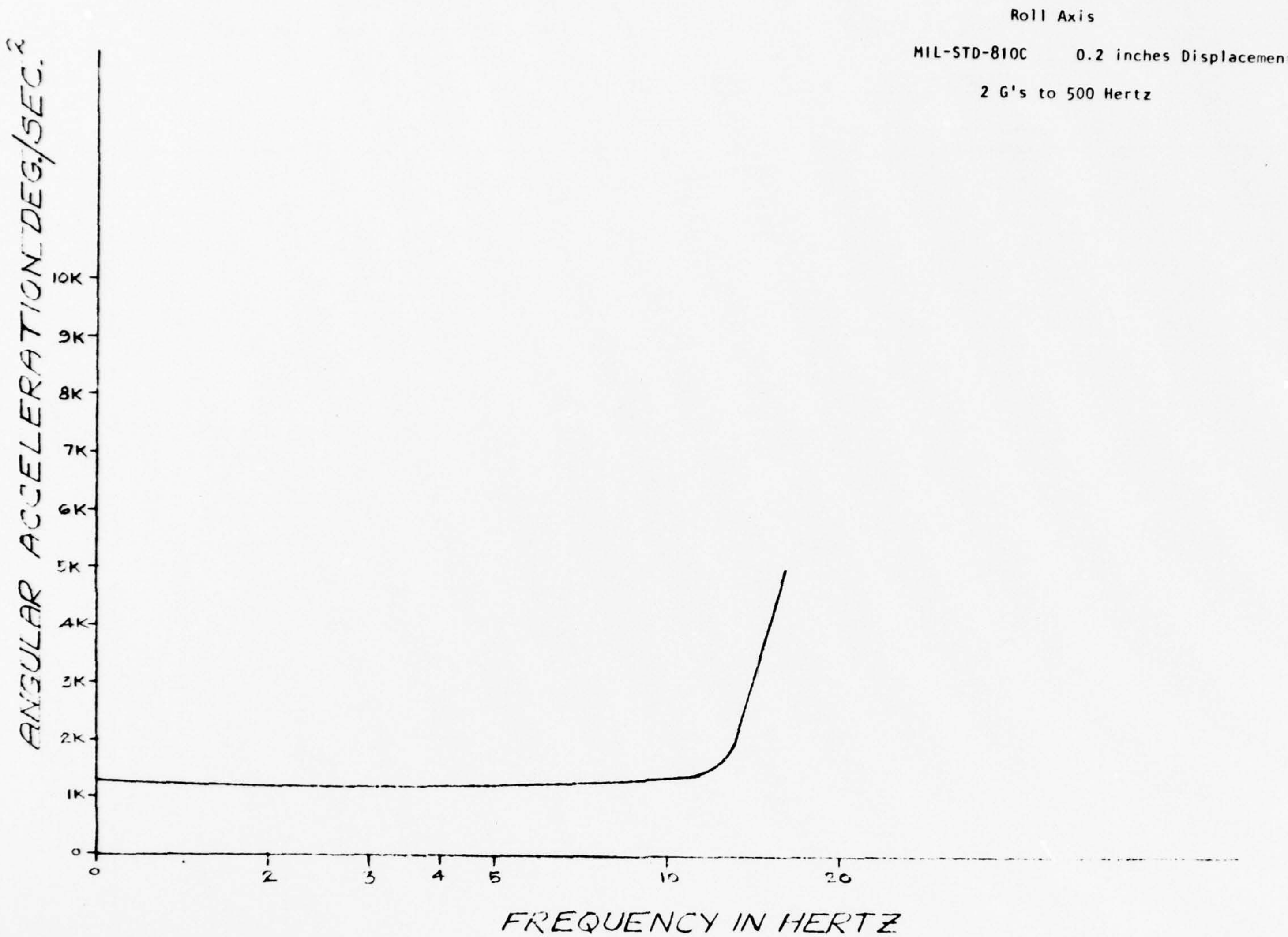


Figure 51. FMS Roll Axis Angular Acceleration Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

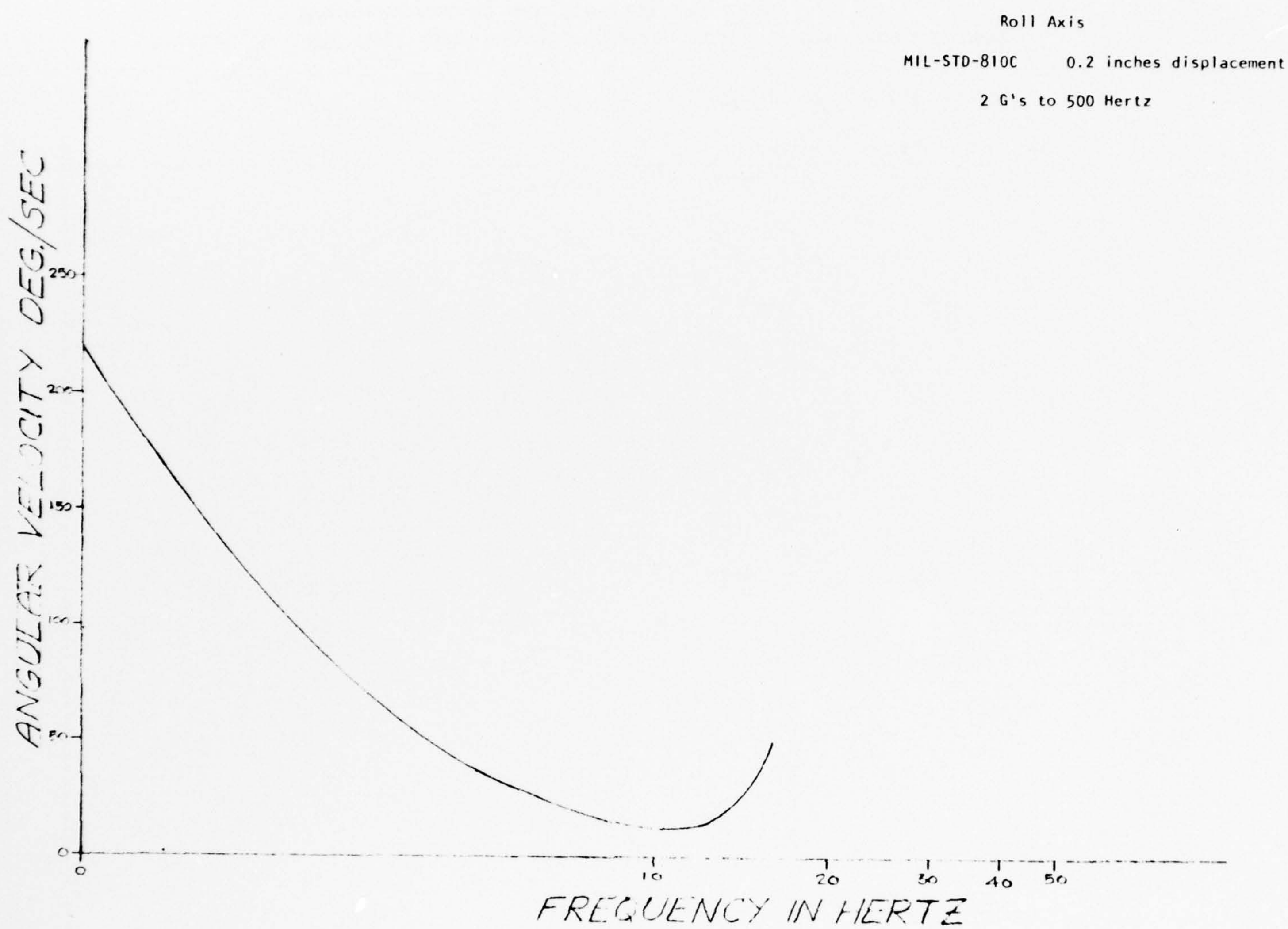


Figure 52. FMS Roll Axis Angular Velocity Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

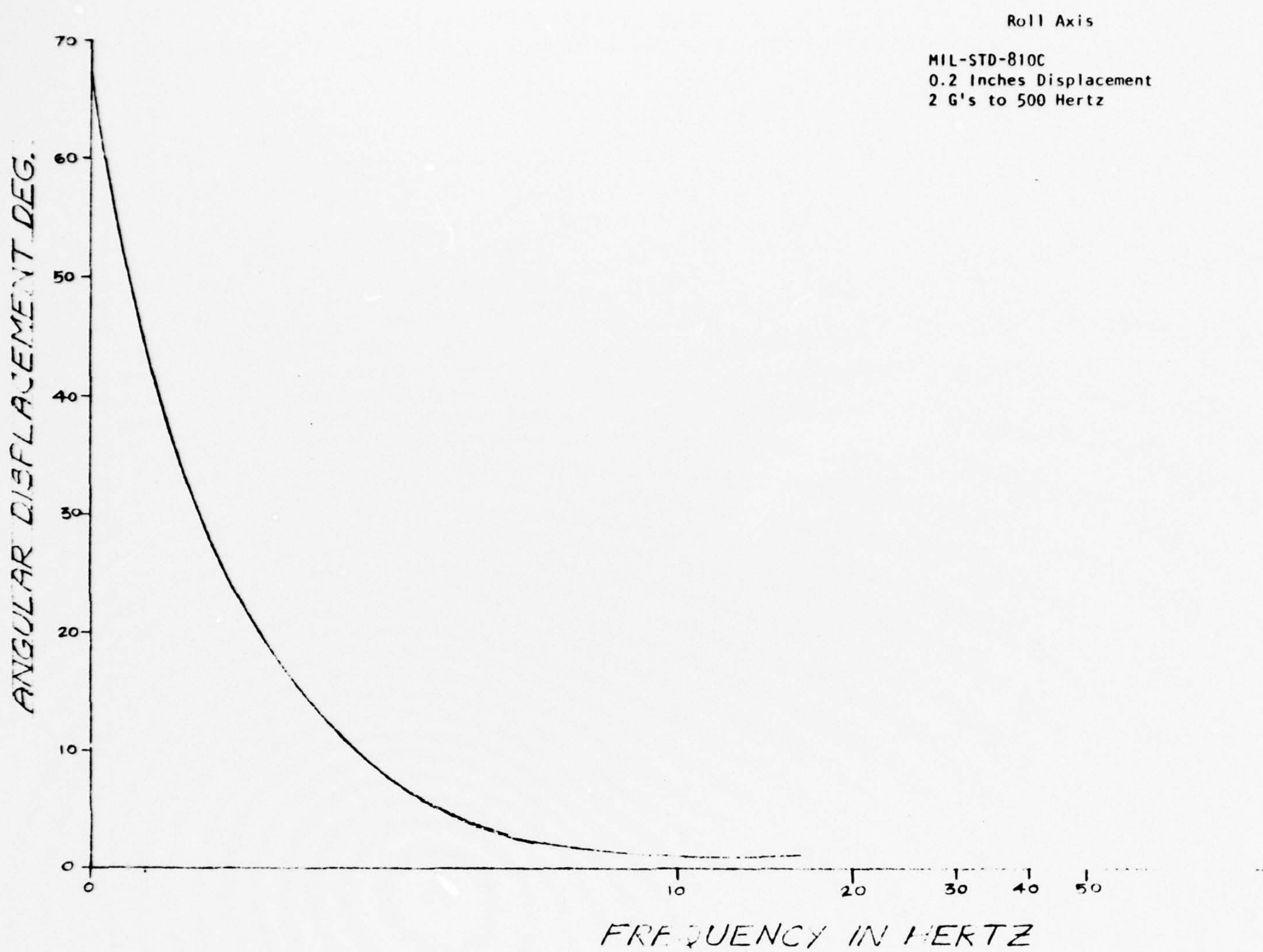


Figure 53. FMS Roll Axis Angular Displacement Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

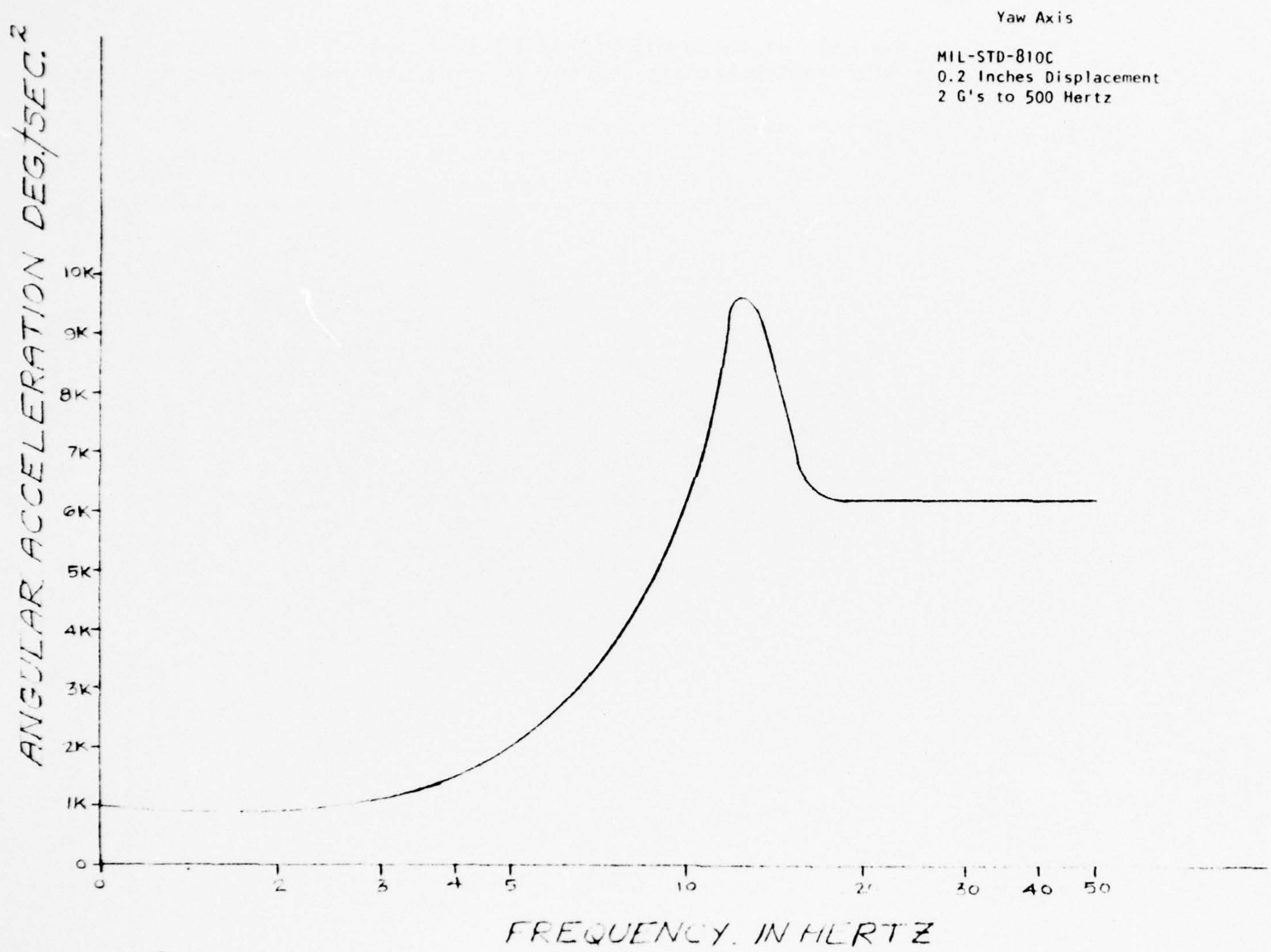


Figure 54. FMS Yaw Axis Angular Acceleration Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

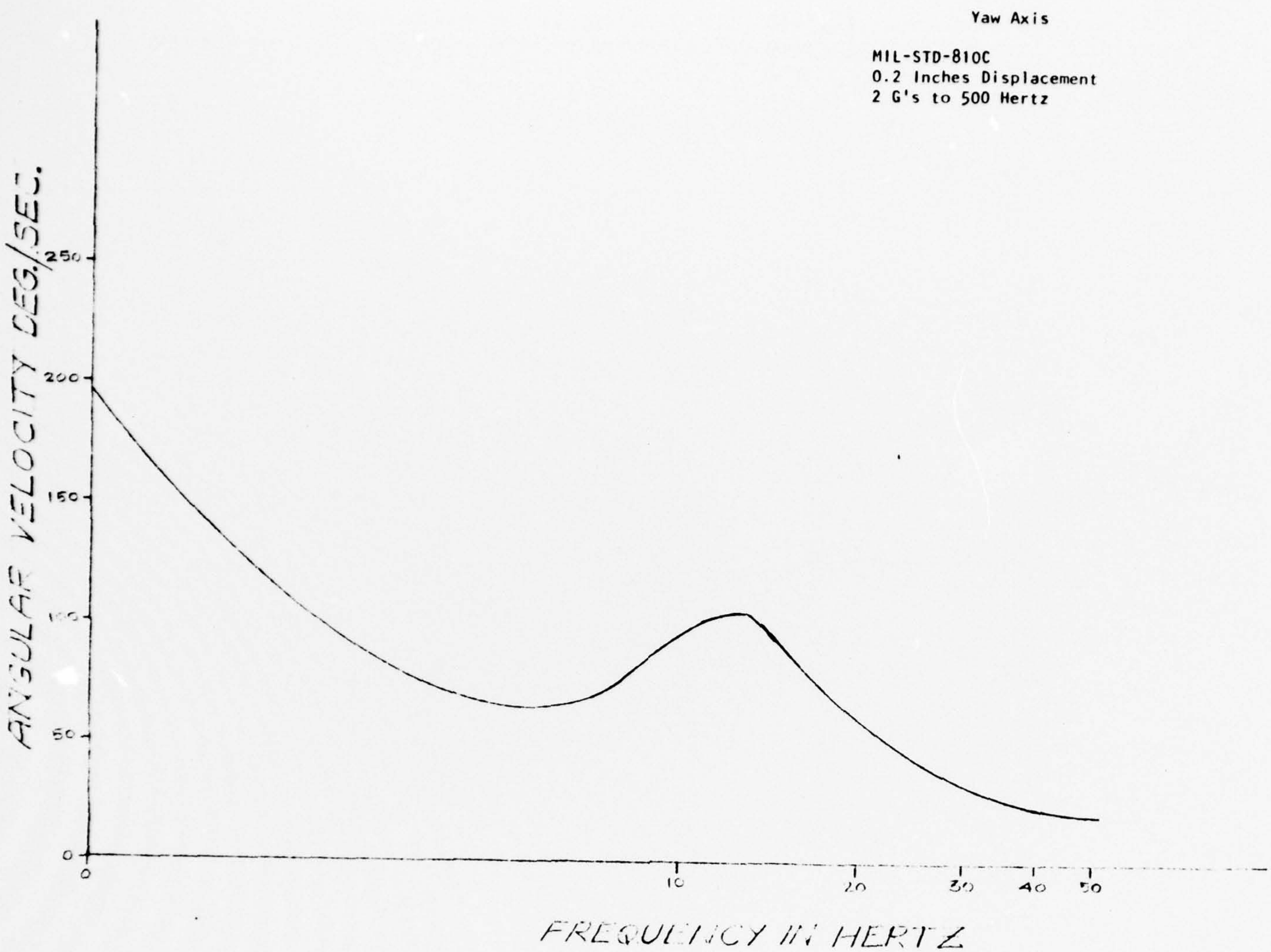


Figure 55. FMS Yaw Axis Angular Velocity Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

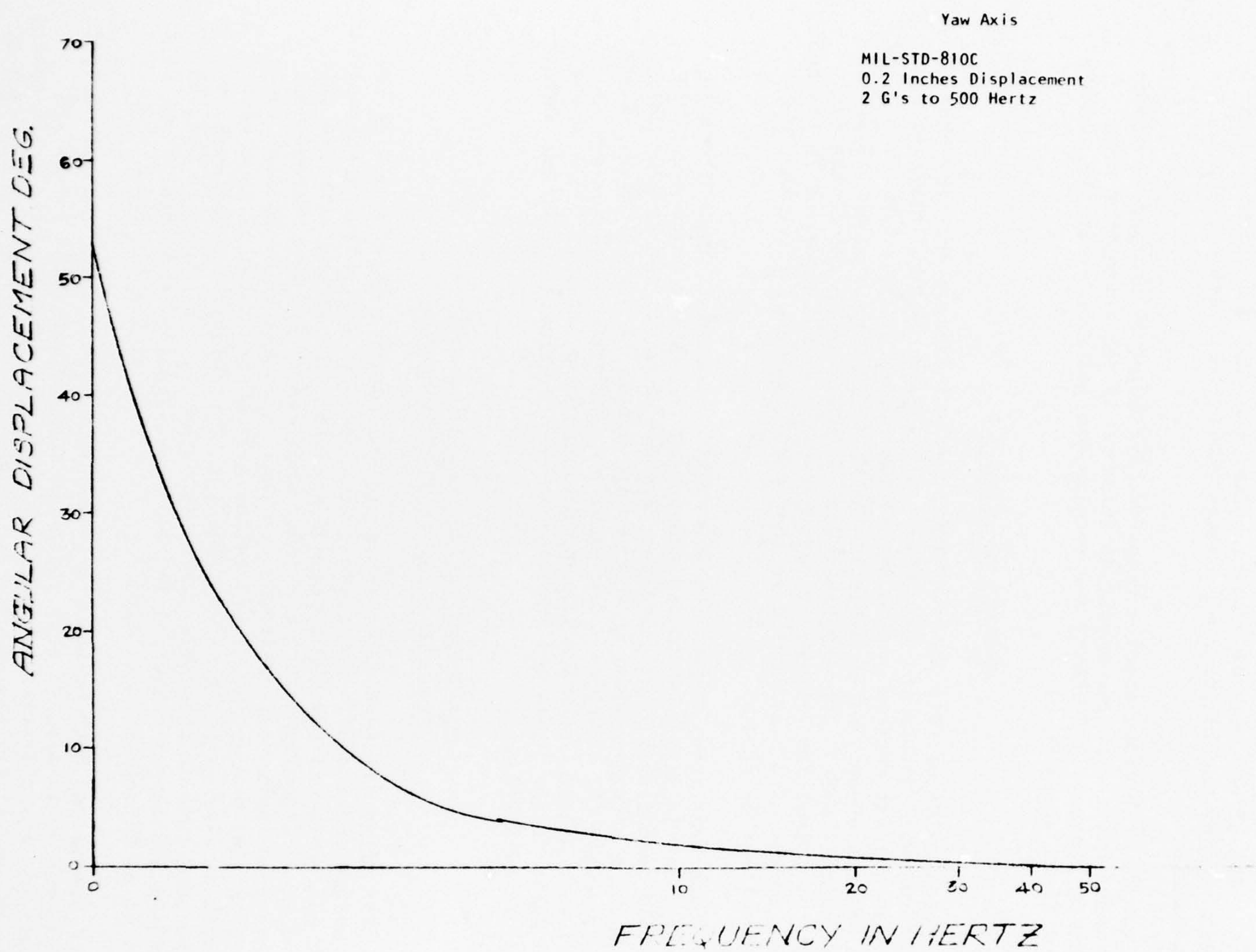


Figure 56. FMS Yaw Axis Angular Displacement Simulation of Linear Requirements of MIL STD 810C Fig. 514.2-3

b. The effect of cross-coupling from the roll and yaw axis into pitch, and by implication, all cross-coupling combinations are negligible.

c. The vibration spectra recorded in Figures 44 thorugh 47 demonstrates that the output amplitude response is not attenuated more than 30 percent at 20 Hertz and remains near or much above the 50 percent level at 33 Hertz.

RESULTS OF PHASE 3

The results of this phase of the program indicates that the FMS performs well within its specified capabilities and will transmit the 3 axis angular motions sensed on helicopters in flight, limited only by an upper frequency of 50 Hertz in the Pitch and Yaw axes and 20 Hertz in the Roll axis. The limitations of 50 Hertz in the Pitch and Yaw axes is normal for the FMS, however, the 20 Hertz limitation in the Roll axis indicates a malfunction in that particular axis which should be correctable by repair.

Using test requirements for equipment installed in helicopters as called out in MIL-STD-810C and converting the linear requirements to angular requirements by using the formulas shown in the body of this report, the curves shown in Figures 48 through 56 were plotted. These curves show the ability of the machine to maintain the requirements of 0.1 inch double amplitude in displacement and a level of 2 G's through 50 Hertz in the Pitch and Yaw axes and to 20 Hertz (explanation above) in the Roll axis.

CONSIDERATIONS FOR DESIGN OF A NEW IMPROVED FLIGHT MOTION SIMULATOR

The first discrepancy noted in the FMS used for this study was the presence of some higher frequency components in the output response that do not appear in the input command signals. The effect noted is small and would actually create a harsher environment for the systems under test than the actual environment. This is caused by mechanical resonances that appear in the simulation system structure. This effect could be greatly mitigated by redesign to provide more stiffness in the structure of the table. Some improvements could also be made by adding additional filtering in the input commands, but this is not felt to be as effective as eliminating the source of the effect.

The second discrepancy was that periods would occur when the output response would drop to zero while the command was still requesting motion. Investigation revealed that this was caused by the table moving to the end of its travel and being unable to respond beyond that point.

This in turn was caused by small very-low-frequency inputs that required the table to move away from its normal position. The effect was generally created by drifts within the system electronics. The basic problem can be eliminated by designing the system electronics so that DC and very-low-frequencies cannot be applied to the table. These features could be included in redesign without difficulty.

DISCUSSION OF TEST AND MONITORING TECHNIQUES

The following are some test and monitoring techniques which have been established for fire control instruments used in the AH-1G "Cobra" helicopter. These have been established by an analysis of prerecorded tapes of the helicopter's motions.

The tape used for this study contained Rate information which had been recorded during a previous test performed on the AH-1G "Cobra" helicopter. An analysis of this tape reveals predominant frequencies of 11, 22 and 33 Hertz and angular rates of approximately 7½ degs./sec. maximum as shown in Figures 38 through 43. These parameters are representative of motions transmitted to Fire Control instrumentation mounted in the AH-1G "Cobra" helicopter. In using the FMS to subject Fire Control instrumentation to vibration tests these parameters may be adopted as part of the test requirements for any particular piece of Fire Control instrumentation to be used in the AH-1G helicopter. The values desired can be fed into the FMS's electronic control console through the manual mode of operation for the desired vibration output at the FMS's table. In the Manual Mode of Operation complex periodic signals are synthesized by means of the three Function Generators and associated circuitry. The associated circuitry permits separate, independent phase and amplitude control for each of the three control axes.

Another method of getting desired vibrations at the FMS's output table is through use of the Tape Mode of operation. In this mode of operation inputs to the FMS are derived from three tracks of magnetic tape recordings, each representing an orthogonal component of angular rate sensed on an aircraft in flight. (For special purposes a prerecorded synthesized signal could be used in the Tape Mode. It should be remembered, however, that the tape signals will command proportional table rates.)

Additional benefits of utilization of the available three-axis angular motion simulator is that it will permit in-house simulation of operational use of manufactured fire control for helicopters. As a readily available environmental simulator to engineering personnel, it will be extremely useful in checking fire control instrument quality and effectiveness of manufacturing modifications, obviating many hours of live flight testing and the attendant dangers involved therein. Installation of improved three-axis motion simulators at selected government and manufacturing facilities, will provide vital support for assuring manufacturing quality of fire control for helicopters.

CONCLUSIONS

The four objectives of this program as specified in the introduction have been successfully accomplished. A thorough calibration of the FMS throughout its entire range of capabilities was performed. It has been determined that through use of pre-recorded tape data the FMS will closely simulate helicopter motion. It has been determined that existing specifications for fire control instrumentation for use in a helicopter can be met (up to a frequency of 50 Hertz) by using the FMS. The most undesirable characteristics which can be designed out of a new improved FMS have been specified.

APPENDIX A

OPERATION CHARACTERISTICS OF THE FLIGHT MOTION SIMULATOR

A. Power Requirements

Control Console Power	110V, 60 Hz, 3 AMPS
Tape Console Power	110V, 60 Hz, 2 AMPS
Hydraulic Power Unit	208V, 3 phase, 60 Hz, 70.2 AMPS

B. Test Specimen Specification

Inertia (About each Axis)	20 lb-inch-sec^2, max
Size and Weight	20 in. diam, height & weight limited by inertia

C. Table Motion Specification, each axis, maximum load:

Angular Displacement	$\pm$ 10 deg. max
Angular Velocity	$\pm$ 314 deg/sec. max
Angular Acceleration	$\pm$ 20,000 deg/sec^2, max
Amplitude Attenuation with Frequency	30% @ 25 Hz
Servo Valve Rating	26 $\frac{in^3}{Sec}$
Servo Valve Scale Factor	5.2 $\frac{in^3}{Sec/ma}$
Position P/O Excitation	17 V peak, 5 KHz, Nom.
Position P/O Scale Factor	4.2V peak/in. 5 KC, Nom.
Accumulator Precharge	1500 Psi, Min 2000 Psi, Max.
Accumulator Capacity	1.0 Gallon, Nom.

APPENDIX A (Cont)

D. Control Servos (one per Axis)

Function Generator Input S.F.	
(3 per Servo Card)	.045 Volts/Deg. Nom.
Centering Signal S.F.	1.0 Volt/Deg. Nom.
Tape Signal S.F.	1.0 Volt/Deg. Nom.
Position Cmd S.F.	1.0 Volt/Deg. $\pm 5\%$
Position Cmd Range	$\pm$ 10 Deg.
Table Pos R/O S.F.	.566 Volts/Deg. $\pm 5\%$
Table Rate R/O S.F.	0.1 Volts/Deg. $\pm 5\%$

E. Function Generator (3 per system)

Waveshaper	Sinusoid, Square, Sawtooth
Frequency Range	.05 Hz to 100 Hz
REF Sinewave	5V Peak
Synchronizing Signal	-10V peak, 5 sec. dur.
Amplitude (3 independent controls per F.G.)	± 10 Deg's
Phase Adjustment (3 independent controls, for sine waveshape only)	$0\text{-}360^{\circ}$

F. Tape Conditioner (1 Channel/Axis)

Tape Input Scale Factor	.05 V $\frac{\text{V-Sec.}}{\text{Deg}}$ Nom.
Tape Output Scale Factor	1 V/Deg, Nom.

G. Tape Console

FM Playback Output	10V, Max.

Tape Speeds, (with spool change)	(15 ips)

H. Hydraulic Power Unit

Pressure	3000 PSI
Reservoir Capacity	60 Gallons
Maximum Operating Temperature	150°F
Flow Rate	12 GPM

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